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WESTERN AMERICANA

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IRRIGATION
AND
SETTLEMENT
IN
AMERICA

BY

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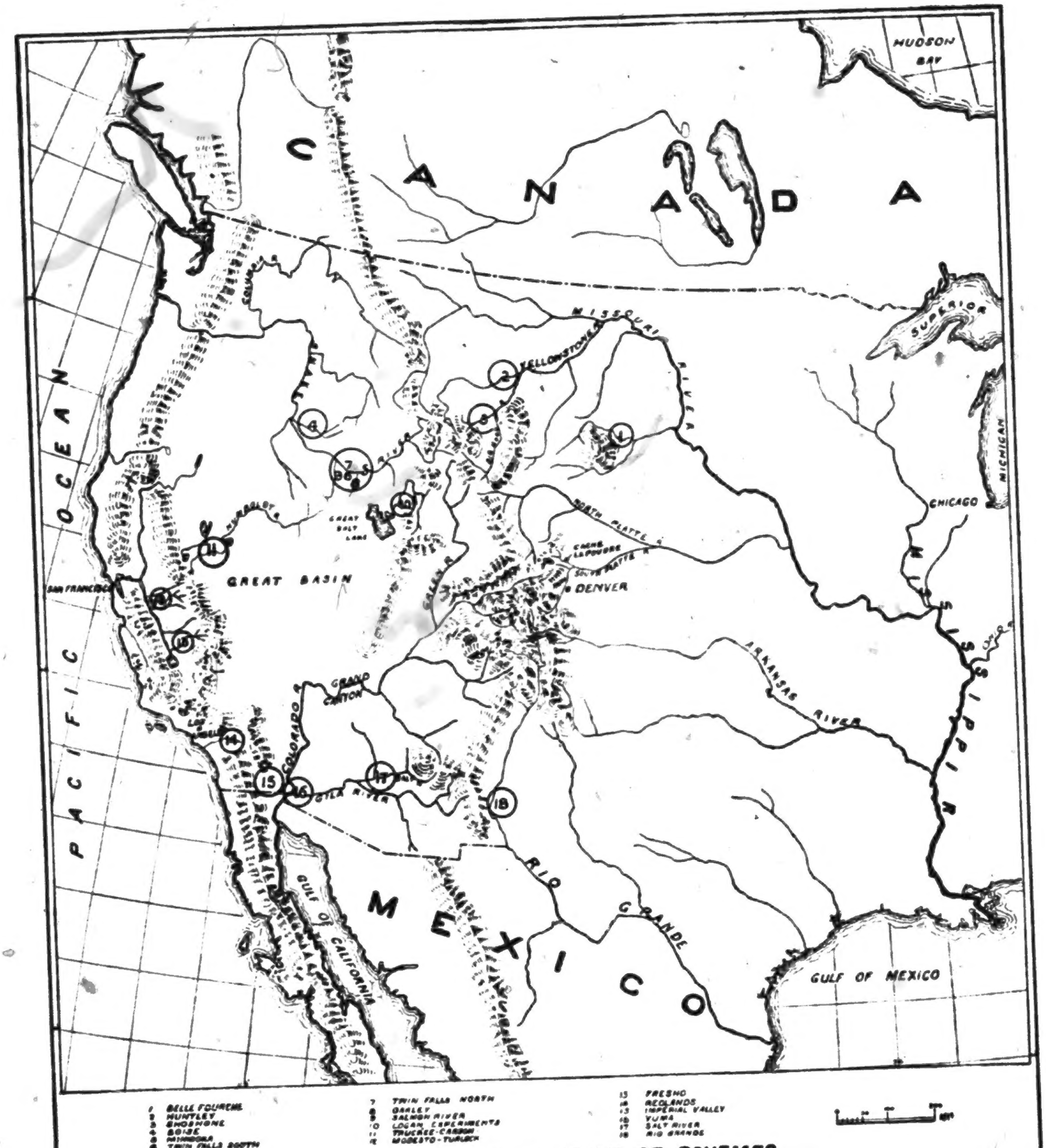

HUDSON BAY
CANADA
SUPERIOR
MICHIGAN
CHICAGO
MISSOURI RIVER
YELLOWSTONE R.
NORTH PLATTE R.
CACHE LA POUDRE
SOUTH PLATTE R.
DENVER
ARKANSAS RIVER
MISSISSIPPI
PACIFIC OCEAN
GREAT BASIN
GREAT SALT LAKE
SAN FRANCISCO
HUMBOLDT R.
SNAKE RIVER
GRAND CANYON
COLORADO R.
GILA RIVER
RIO GRANDE
MEXICO
GULF OF CALIFORNIA
GULF OF MEXICO
1 BELLE FOURCHE
2 HUNTLEY
3 SHOSHONE
4 BOISE
5 MINIDOKA
6 TWIN FALLS SOUTH
7 TWIN FALLS NORTH
8 OAKLEY
9 SALMON RIVER
10 LOGAN EXPERIMENTS
11 TRUCKEE-CARSON
12 MODESTO-TURLOCK
13 FRESNO
14 REDLANDS
15 IMPERIAL VALLEY
16 YUMA
17 SALT RIVER
18 RIO GRANDE

— MAP SHOWING POSITION OF SCHEMES —

Fig. 1.

PREFACE

Irrigation has made very rapid strides in America during recent years, and other countries similarly situated can derive much useful information from a study of the results achieved.

From the purely engineering point of view many valuable lessons may be learnt, particularly in the methods of constructing high masonry or earthen dams, in the design of valves for high dams, and in methods of draining seeped lands; but perhaps even more valuable lessons are to be derived from the results of settlement, for there is no other country where so much has been done to establish by means of irrigation homes for a white race in arid or semi-arid regions.

In the following pages I have attempted to describe seventeen of the more modern irrigation schemes which I inspected on a tour through the West during September, October, and November, 1913. The schemes are arranged in the order in which I visited them, beginning in the north and ending in the south, as shown by the numbers on fig. 1.

Most of the books on American irrigation are written in the manner of textbooks, each general principle being illustrated by examples from several schemes. Many of them, too, deal with only one aspect of irrigation, such as engineering. This volume has, therefore, been written with the feeling that there may be room for a book describing a number of schemes, each separately in all its aspects, and with special reference to the results achieved in settlement, which is, after all, the measure of the success of irrigation and depends on conditions which vary with each scheme. Failures in irrigation schemes have resulted, not so much from bad engineering, as from lack of a proper understanding of the agricultural conditions and of all that is involved in the human aspect of settlement. I have, therefore, not confined myself to the engineering side, and have treated each scheme separately.

At the same time a uniform method of description has been followed in most of the schemes, so that information on any one aspect of irrigation can be conveniently found and brought together for comparison.

The general order is as follows:—

Physical conditions, outline of scheme, engineering works of interest, soil and agricultural conditions, settlement and cost, distribution and duty of water.

One chapter describes some useful crop experiments in Utah, and two chapters towards the end deal with settlement and irrigation law. It would probably be advisable to read the chapter on settlement first, so as to understand the conditions on schemes carried out under the Reclamation Act and the Carey Act. Some of the more important general features of the schemes described have been gathered together in the last chapter, but not in tabular form, which might have been misleading on account of the number of variable modifying circumstances in each scheme.

Contours have been given on most of the maps, in order to indicate the surface-slope, which has such an important bearing on the methods adopted for the actual application of water to the land. The contours are in some cases only approximate, but still they give more information than indefinite phrases to describe different degrees of "flatness."

In order to avoid vague words in the description of soils, and to facilitate comparison with the soils of other countries, the physical analysis has been given wherever obtainable.

Considerable vagueness is also common in describing methods of applying water to the land, particularly in the use of the expression "flood-irrigation." I have therefore used the following expressions for the methods most frequently adopted:—

(1) "Simple surface-flow," when the water, after leaving the ditch, simply runs down the slope without any restraint except by short guiding walls irregularly thrown up by spade.

(2) "Surface-flow between borders," when the water runs down the slope but is confined by parallel borders and usually by cross borders or drains at the bottom. This is by far the commonest method in America.

(3) "Basin-soakage," when the water is headed up in basins completely enclosed by walls. This method is common on heavy flat land.

(4) "Furrow" or "corrugation," when the water is run down the land in a series of small furrows, usually about a yard apart. This is a common method for orchards, vegetables, etc., or where the soil is light and the slope steep.

Another expression requiring explanation is "application," which I have used to express the depth of water applied to the land in the same way as rainfall. Information given in this way as to the use of water, when combined with information as to the times when different crops require water and as to wastage in canals, is more useful than when given in the usual form of "duty."

Figures of cost have been given in dollars and cents. For approximate conversion, 1 cent may be taken as equivalent to ½d., and $1 to 4s. 2d. Roughly, to turn dollars into pounds, divide them by five.

For permission to use photos I am indebted to Mr. Bisbee, of Twin Falls; the West Coast Photo and Art Co., and Messrs. Kellar Thomason, of Los Angeles; the Director, U.S. Geological Survey; the American Society of Civil Engineers; and particularly to the Director of the U.S. Reclamation Service for all photos of reclamation schemes.

I cannot adequately express my acknowledgments to all officers of the Reclamation Service, directors of companies, and other officials for the kindly assistance extended to me on every scheme I visited, especially in transport facilities and opportunities for inspecting works and plans.

Much of the information in the following pages was collected on the spot, but numerous publications have been consulted, and I am particularly indebted for valuable information to the excellent annual reports of the Director of the United States Reclamation Service, the transactions of the American Society of Civil Engineers, and a number of articles in the *Engineering News*, *Engineering Record*, and other periodicals.

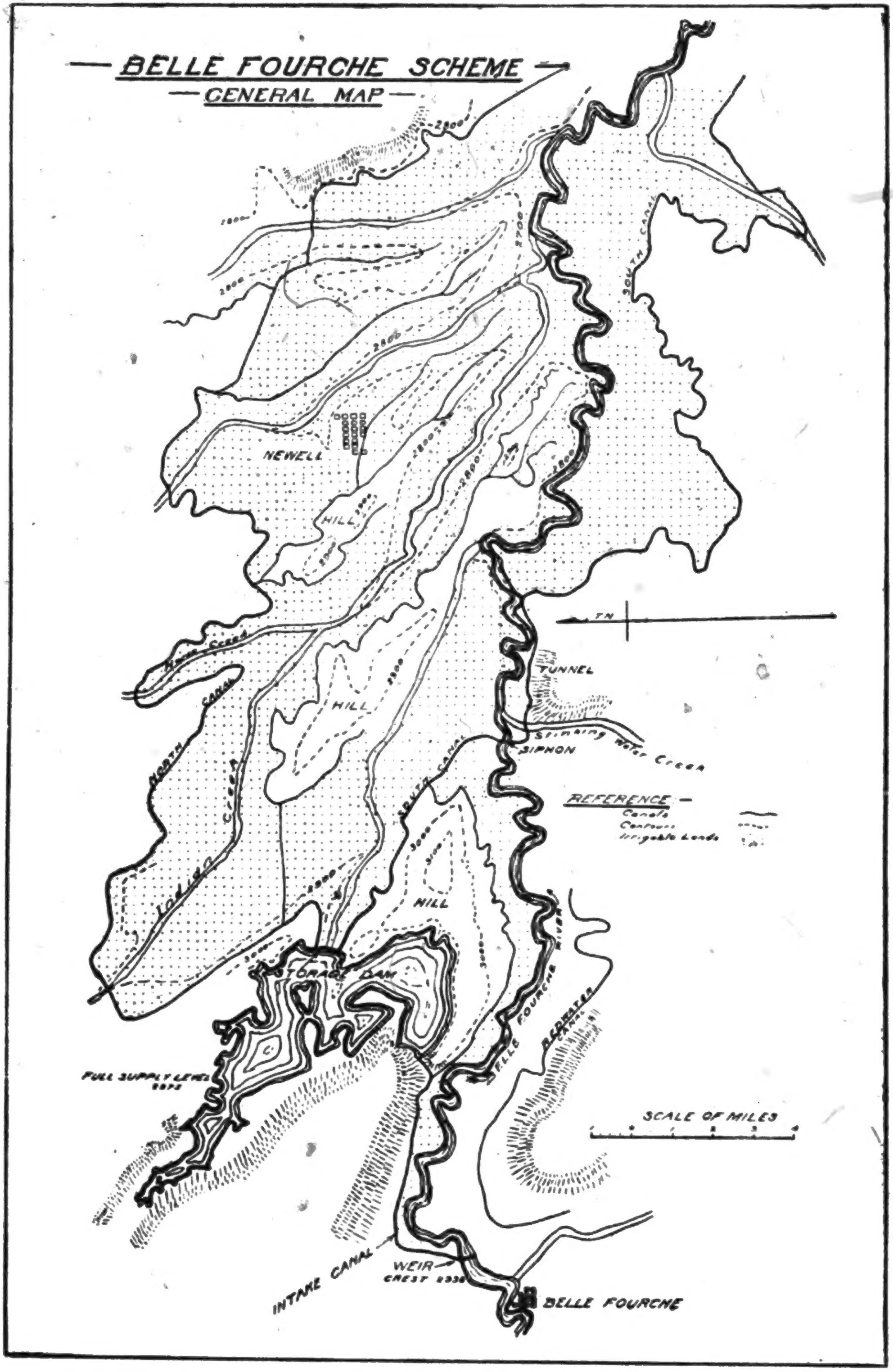

BELLE FOURCHE SCHEME
GENERAL MAP
2800
2700
2900
3000
NEWELL
HILL
HILL
HILL
SOUTH CANAL
NORTH CANAL
Indian Creek
TN
TUNNEL
Stinking Water Creek
SIPHON
REFERENCE —
Canals
Contours
Irrigable Lands
STORAGE DAM
FULL SUPPLY LEVEL
BELLE FOURCHE RIVER
REDWATER CANAL
SCALE OF MILES
INTAKE CANAL
WEIR
CREST
BELLE FOURCHE

Fig. 2.

CHAPTER I

THE BELLEFOURCHE SCHEME

(United States Reclamation Service, South Dakota)

Locality.

THIS scheme is situated near the western boundary of the State of South Dakota at an elevation of about 2800 feet. It derives its water from the Bellefourche River, which rises in the Black Hill Mountains and runs thence easterly through the irrigated area to join a tributary of the Missouri River.

The hills adjoining the irrigable area are low and consist largely of blue and brown shales (Pierre shales) with layers of gypsum. The formation has much the appearance of the Ecca shales as seen in the north of the Calvinia District of South Africa, though the former series is geologically much younger, being correlated with the Upper Cretaceous. It weathers easily on exposure and crumbles into small soft flakes, in this respect also resembling the Ecca shales.

The natural growth of the area is a low sage bush (*atriplex*), and along the rivers and creeks cottonwood trees (like poplars) are abundant. Winter temperatures of −30° F. have been recorded, and during four of the winter months the mean temperature is below freezing point. The cold weather is frequently broken up by the warm south-west "Chinook" wind. In summer the temperature sometimes rises to 100° F. The sky is seldom cloudy and winds are usually strong.

Rainfall and Water Supply.

The average rainfall on the irrigable area is about 15 inches, the wettest period being in spring and early summer. Thunderstorms are rare. The drainage area is steep and not very thickly covered with vegetation, and consequently the run-off from rains is rapid and the peak of floods resulting from rain is of short duration.

The drainage area above the diversion works is 4265 square miles, and the mean annual run-off is 291,000 acre-feet, the maximum and minimum observed being 477,000 and 123,000 acre-feet. A table of mean monthly flow would be somewhat as follows:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.
Cusecs:	Ice.	Ice.	500.	500.	600.	1100.	400.	250.	200.	300.	300.	Ice.

As the whole area to be irrigated by the completed scheme is 100,000 acres and the irrigating season extends from 1st May to near the middle of October, it is obvious that storage must play an important part in the scheme.

Outline of Scheme.

The main features of the scheme are shown on fig. 2, page 8. A weir across the Bellefourche River raises and diverts the water into a canal 6½ miles long, which feeds the large storage reservoir and also supplies a small furrow for direct irrigation of part of the lands. From the reservoir one main canal runs round the upper edge of the lands on the left, which slope down towards the river, and another canal crosses the river to irrigate a smaller area on the right bank.

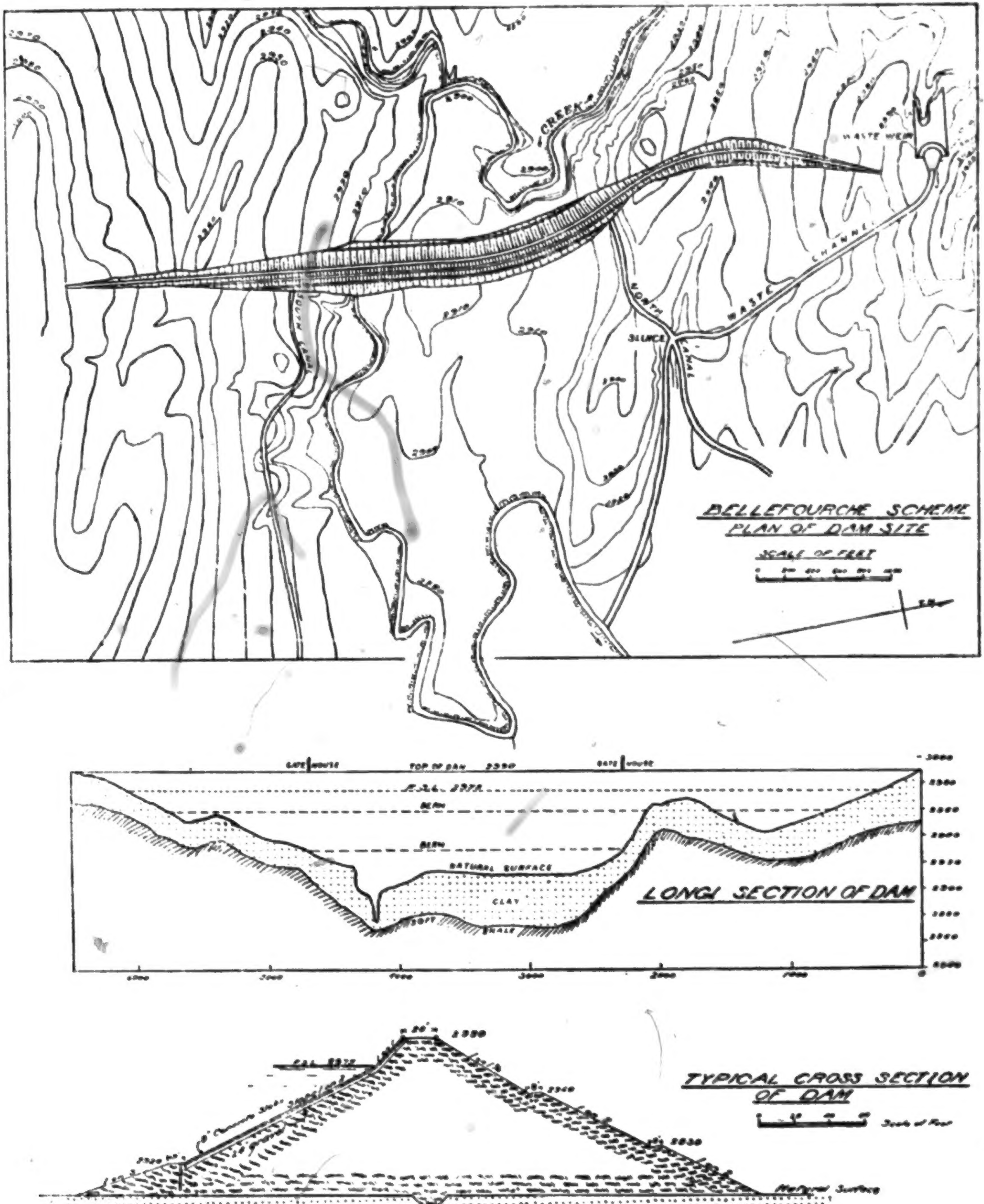
Engineering Works.

Headworks.

There is nothing very remarkable about the headworks. The diversion-weir is 400 feet long and has a maximum height of 23 feet above the bed. It is founded on shale and is of concrete with vertical up-stream face, 6 feet top-width, 1 on ¾ down-stream face, and a long apron from the toe protecting the shale, which is liable to weather on exposure. At the end of the weir are three scouring sluice-gates, each 5 feet wide and with sill 13 feet below the crest of the weir. Immediately adjoining them, and at an angle of 45 degrees to the line of the weir, are the canal regulator-gates with sills 2 feet higher. There are seven of these gates, each 5 feet wide by 10 feet high (see photo A, plate 1). The intake-canal has a bed-width of 40 feet, a full-supply depth of 10 feet, a grade of 1 in 5000, and is capable of carrying 1650 cusecs. It runs through comparatively easy sidelong ground, and at the end of 6½ miles cuts deeply through a neck in the ridge separating the river valley from the parallel storage basin into which the canal drops over a masonry weir to prevent scour in the canal above.

Storage Reservoir.

This is the most interesting feature of the scheme, being one of the largest earthen embankments ever made without any sort of core-wall. The maximum height above the bed is 115 feet. The water stands back 8 miles, covering an area of 8000 acres when the reservoir is full.



BELLEFOURCHE SCHEME
PLAN OF DAM SITE
SCALE OF FEET

LONGL SECTION OF DAM

TYPICAL CROSS SECTION
OF DAM

CREEK
WASTE WEIR
NORTH
WASTE
CHANNEL
SLUICE
GATE HOUSE
TOP OF DAM 2990
GATE HOUSE
F.S.L. 2972
BERM
BERM
NATURAL SURFACE
CLAY
SOFT
SHALE
20'
2990
F.S.L. 2972
Scale of Feet
Natural Surface

Fig. 3.

The capacity is 210,000 acre-feet, of which 204,000 acre-feet are available. The chief dimensions of the dam are given in fig. 3. It is 1¼ mile long on the crest, and contains 1,600,000 cubic yards of earthwork. The line of the dam is curved to economize material. The dam is built on a tough heavy clay soil, known locally as "gumbo," which extends uniformly to a depth of from 10 to 40 feet, and overlies a shale, soft on top, but harder below. The surface was cleared of all growth and ploughed to a depth of 8 inches. The material for the dam was brought on by rail from borrow-pits in the hills near the extremities of the dam, and was deposited in layers of 6 inches, watered and rolled. The up-stream face is strongly protected because of ice-action and the great depth and reach of the water in the direction of the prevalent strong winds. The pitching consists of 12 inches of coarse gravel covered by 12 inches of screened gravel. On top of this, concrete slabs, 6½ feet by 5 feet, are laid 8 inches thick, extending from a berm below low water to a short distance above high water and then 6 inches thick to the top. The slabs were made away from the site and placed in horizontal layers bedded without mortar on the gravel and with open joints not exceeding half an inch. In spite of these precautions a storm caused by a heavy wind in April, 1912, carried away a considerable length of the pitching, and, to prevent further damage and effect repairs, a large volume of stored water had to be released. The down-stream slope of the dam has been covered with 12 inches of surface loam, fertilized and seeded with special grasses to prevent scour. For the same purpose two shallow open drains of concrete have been built on 8 feet berms running along the down-stream face of the dam. They would carry off the rainfall on the bank but for the washing-in of the soil, the slope of the gutters being insufficient to carry this along. No base-drains were provided in the original structure, but as the ground immediately below the dam became swampy, a 12-inch drain was later on placed parallel to the axis near the down-stream toe and about 15 feet below the original surface. This now discharges an almost constant stream of about 50 gallons per minute. Saturation tests were carried out on the dam for twelve months in 1912. Thirty-four 2-inch pipes were sunk in six parallel rows over a length of 100 feet of the dam, and the water level was observed in them. With 57 feet of water in the dam the level in the front row (some way down the up-stream slope) was very variable, the difference of level in two pipes being as much as 40 feet. In the row on the line of the up-stream edge of the crest, the water level varied from original ground level to 28 feet above it; half-way down the down-stream slope all holes were dry down to ground level, and near the down-stream toe the level was 10 feet below the ground.

The spillway-crest is 15 feet below the top of the dam. It is a concrete weir of semicircular plan with a radius of 100 feet. Although completed in 1910, the dam has not yet been filled to spillway-level.

Ensign Valves.

Water is drawn from the dam in two reinforced concrete pipes built in the natural soil below the dam, and these can draw water down to 48 feet below spillway-level. "Ensign" patent balanced needle-valves work at the up-stream entrance to the pipes and most regulation is done with them. Lift-gates and stop-planks are also provided in the valve towers. The balanced valves are very ingenious, the enormous surface friction usual in sliding gates under great pressure being eliminated. The valve consists of a simple hydraulic ram working with axis horizontal and in line with the centre of the outlet-pipe. The end of the ram has a conical point which opens and shuts the pipe entrance like a valve of a gas engine, and, on account of its curved shape, when open it allows the water to pass in smoothly. The cylinder is attached to the masonry by gridirons through which the water passes to this pipe. The principle of the valve is illustrated in fig. 4. Photo A, plate 18, and fig. 18 give details of this type of valve. The pressure of the water in the dam tends to open the valve, and, to close it, higher pressure is provided from a tank above full-supply level in the reservoir. The pipe which supplies the high pressure can also release water from the cylinder, as on its way to the valve it comes down to a tap-house at the level of the valve on the down-stream side of the dam. Two taps are provided here. The first, A, turns the high pressure on to shut the valve. The second, B, nearer the valve, opens an escape (while the first is shut) to open the valve. When both taps are shut the valve should remain in one position for long periods. It has been found, however, that leakage is unavoidable, and as it is impossible to provide a clamp, an automatic arrangement has been devised to keep the valve-opening constant at any desired value. The water discharged through the valve is dropped over a weir, and the variation of level above the weir effects the regulation of the valve. A pipe connects the water above the measuring-weir at the head of the canal with a concrete well in the tap-house in which a large float works up and down. On the float are two attachments. Leakage in the cylinder will cause the discharge to increase and the float to rise. One of the attachments opens the tap of the pressure-pipe as the float goes up and thus tends to close the valve, reducing the flow over the

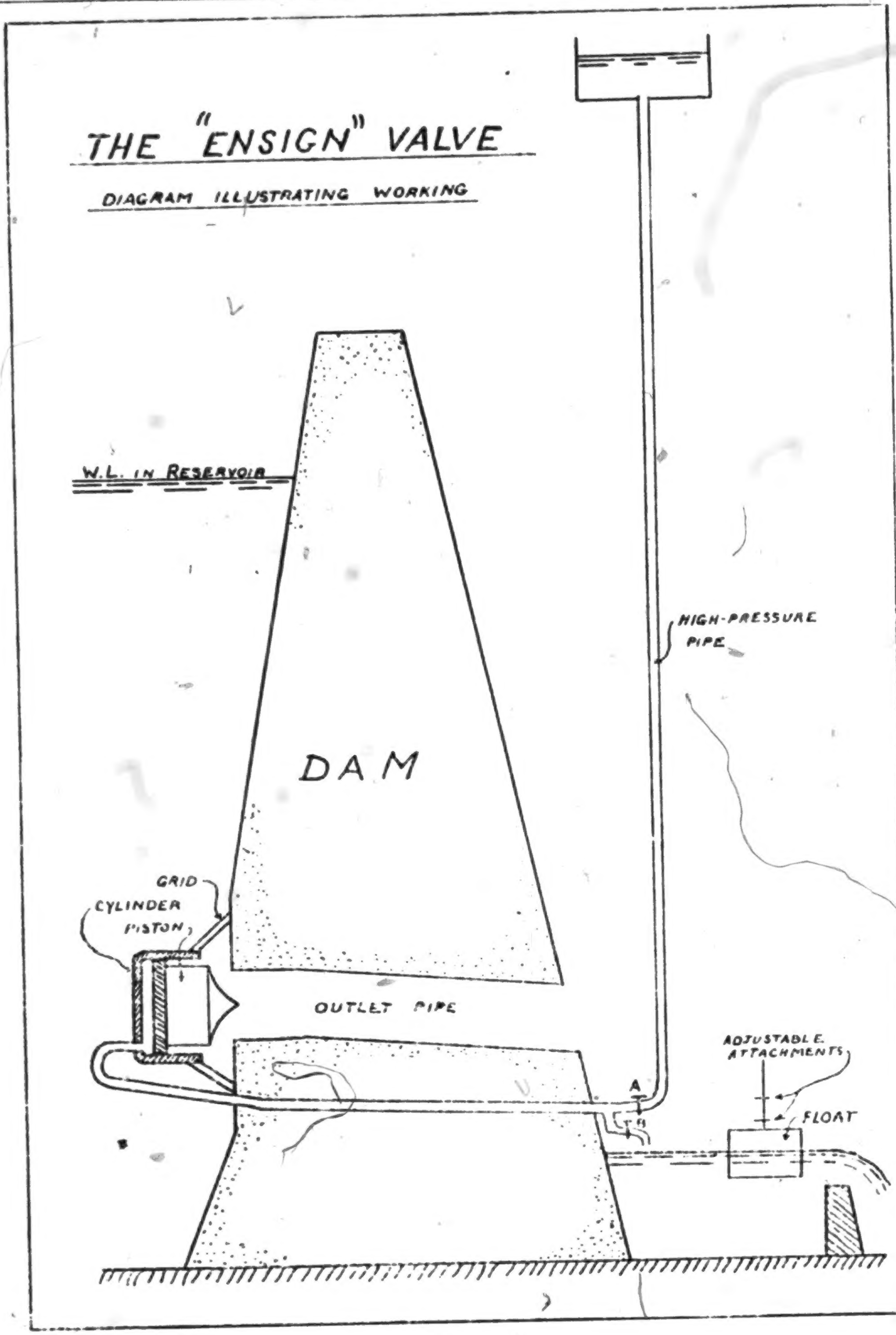

THE "ENSIGN" VALVE
DIAGRAM ILLUSTRATING WORKING
W.L. IN RESERVOIR
DAM
HIGH-PRESSURE PIPE
GRID
CYLINDER
PISTON
OUTLET PIPE
A
ADJUSTABLE ATTACHMENTS
FLOAT

Fig. 4.

measuring-weir and consequently also lowering the level of the water in the well. As the float subsides, its other attachment closes the pressure-tap and opens the escape-tap and the above processes are reversed. By adjusting the position of the float attachments, constant alternation of a slight opening and shutting of the valve is obtained with very small variations of level in the canal. Only negligible fluctuations are caused in the discharge, which can then be kept virtually constant at any value desired by altering the position of the two attachments to the float. The valves are 56 inches in diameter, and there are two for the north outlet and one for the south. "Ensign" valves have been adopted for the Roosevelt and Arrowrock dams, and in the latter case, owing to an inspection-gallery in the masonry, an additional controlling device is provided (see fig. 18, Boise Scheme).

As an additional precaution, if the fluctuations above the measuring-weir become too great, a float there sets an electric bell ringing in the gatekeeper's dwelling. To make the discharge-weir at the end of the pipe as long as possible, it is built in the form of a rectangle extending some distance down the canal, and the water discharges over three sides.

Distributing System.

The north canal for the first 1500 feet is 40 feet wide at the bottom, and can carry 9 feet of water and 1360 cusecs for rapid discharge from the dam. At the end of this distance the canal crosses the spillway-channel and has an escape into it. Thereafter it has a width of 30 feet on the bottom, 7 feet full-supply depth, a slope of 1 in 5000, and capacity of 660 cusecs for the 67,000 acres on the north side. The length is 45 miles, and the capacity diminishes as the laterals are passed. The Indian and Horse Creeks are crossed by steel flumes of the Hess type, the former 1360 feet long and 10 feet 10 inches diameter, and the latter 676 feet long and 10 feet 2 inches diameter.

The south canal starts with 18 feet bed-width, 5 feet full-supply depth, a slope of 1 in 3333, and a capacity of 280 cusecs for 28,000 acres. The Bellefourche River is crossed by a 5-foot diameter reinforced concrete syphon, 3600 feet long, with 40 feet drop. Two other interesting structures on the south side are Stinking-Water Creek flume, and a tunnel 1300 feet long. The former replaces a culvert which was washed away, and consists of two Maginnis steel flumes of 9 feet diameter.

The laterals and smaller structures do not call for much remark. The steepest grade on laterals is 1 in 1000. Drops are vertical concrete falls, or shoots of open concrete or vitrified pipe. Syphons are wood-stave or ferroconcrete. The former do not give trouble with freezing, the water being left in them in winter with the ends closed by canvas and manure. The ferroconcrete pipes have to be drained in winter and are provided with expansion joints. Flumes are mostly of the Maginnis or improved Hess type, and are cheap and lasting. In some places, where culverts pass under the canal, peculiar escapes are made by building walls oval in plan to full-supply level over a hole in the roof of the culvert. The canal water passes round each side of the oval and escapes over the wall and through the hole when there is excess. The advantage of this type of escape is not very apparent. A number of head-gates to distributaries and minors were of wood, but are now being replaced by concrete and iron. A simple head-gate for minors is made by setting the gate to work parallel to the slope of the bank, the frame being bedded in a concrete slab parallel to the bank, with a short steel circular piece attached horizontally, fitting into earthenware pipes through the bank. Smaller divisions into leading furrows are usually made by simple wooden structures.

Cleaning Furrows.

The larger furrows have not yet required cleaning. The water being clear, there is no silt-deposit, and weeds and moss are not very troublesome. The smaller the channel, however, the greater is the work of cleaning, and some of the smaller furrows have to be cleaned twice a year. The commonest growth in the small furrows is a tall sweet clover. Russian thistle, a small reddish prickly growth, very common over the whole irrigated area, is easily blown out when dry. It gathers in bunches in the furrows and gives trouble at bridges and other obstructions (see photo B, plate 1). A long moss also grows in places well exposed to the sun, but has not given much trouble yet.

Agricultural Conditions.

Soils.

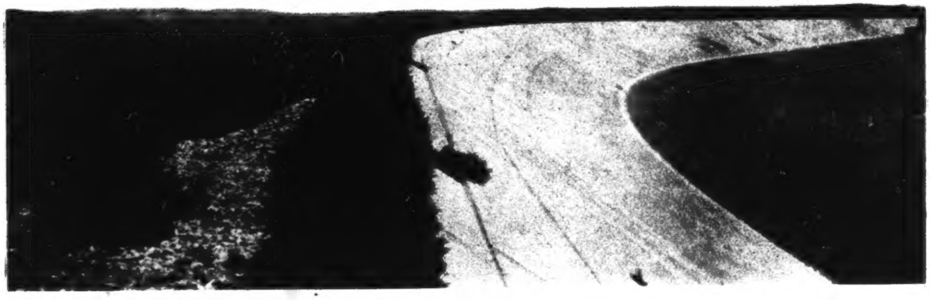
By far the greater portion of the irrigable area consists of a heavy, compact, tenacious clay, known locally as "gumbo." Close to the banks of the river, and on the south side, however, a fine sandy loam predominates.

The following is a comparison of the mechanical analysis of those two types of soil:—

	Fine Gravel.	Coarse Sand.	Medium Sand.	Fine Sand.	Very fine Sand.	Silt.	Clay.
"Gumbo"	0·2	1·1	1·4	5·5	13·0	43·2	35·0
Sandy Loam	0·1	0·7	0·3	8·4	24·5	55·9	10·7

BELLEFOURCHE SCHEME.

(*a*) Headgates of Intake-Canal.

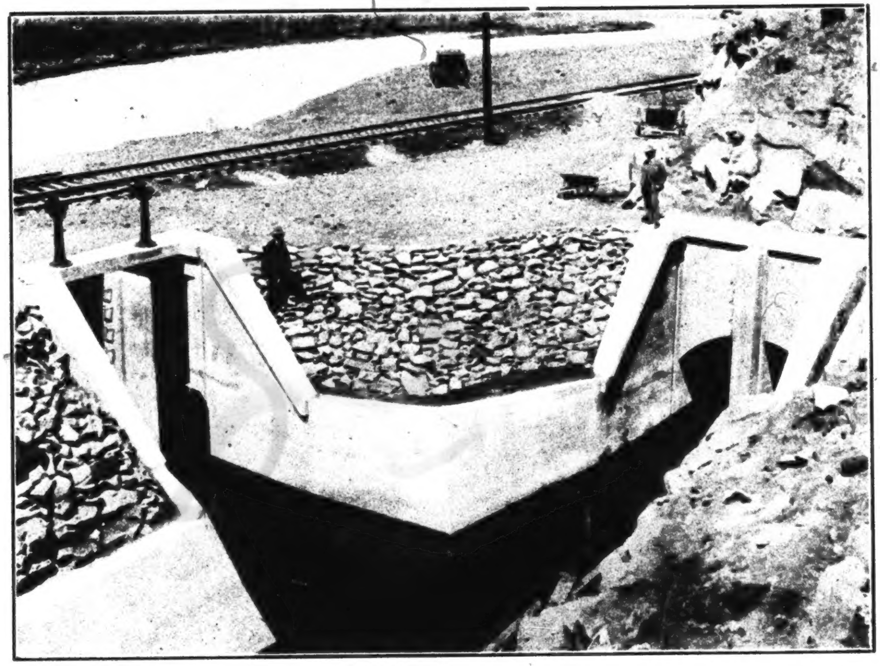


(*b*) Storage Dam. The weed on bank is Russian thistle.

Plate 1.

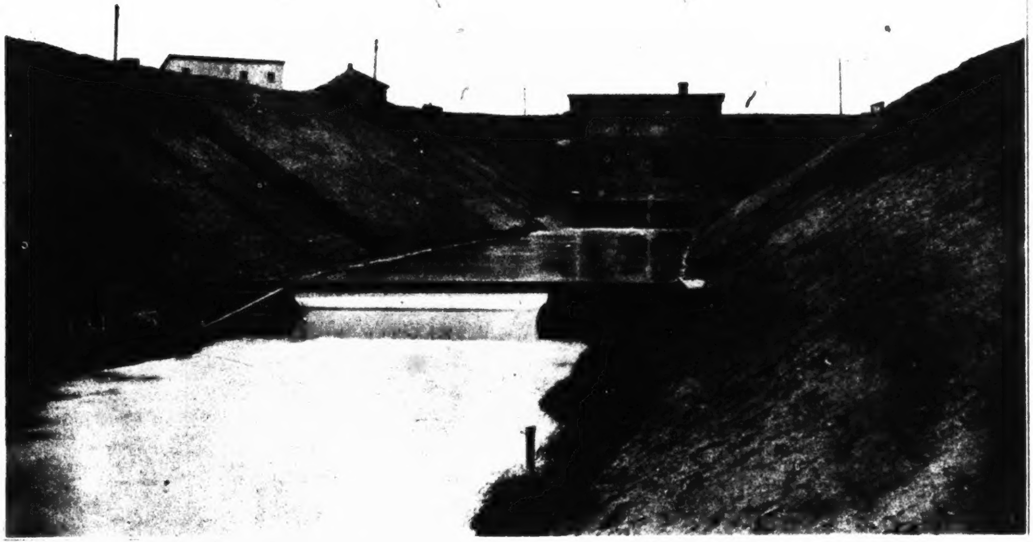
HUNTLEY SCHEME.

(*c*) Natural state of lands on bench under Pumping Scheme.—Sage-bush vegetation.



(*d*) Tunnel Entrance and Sluice to Yellowstone River.

HUNTLEY SCHEME.

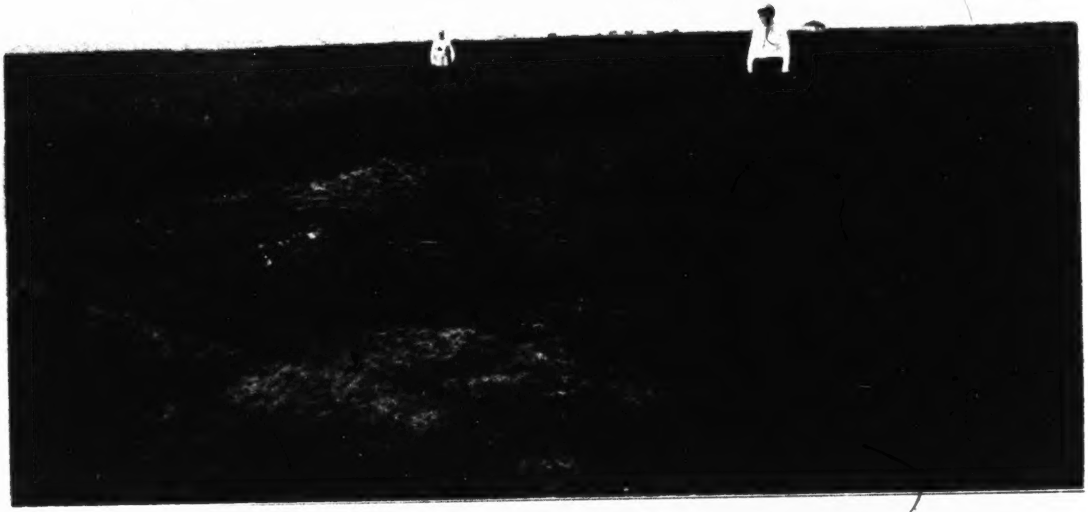


(*a*) Turbine Pumping Plant and Measuring Weir.

(*b*) Bottom of 41 ft. Pipe-drop at 17 miles.

Plate 2.

HUNTLEY SCHEME.



(c) Lucerne—First cutting

(d) Sugar Beets.

Just before my arrival in September, a heavy rainstorm of 2 inches in fifteen hours had passed over the area, and the "gumbo" soil had become so sticky even in the streets that it was quite difficult to walk along them on account of the huge masses of gumbo that stuck to my boots. Wagon wheels caught up so much of it that, after only a few revolutions, they had to be cleaned with a spade. Quite a number of sleighs took the place of wagons over the wet gumbo. The depth of the gumbo soil is, on an average, 6 feet or less, and it rests on the shale with no good under-drainage. Cereals do well in the gumbo, and also lucerne, though it is somewhat difficult to get it established. Alkali is found in most of the clay soils, but not much in the more sandy soils. An average of a number of boreholes over the whole area gave the following results in percentages:—

	1st foot.	2nd.	3rd.	4th.	5th.	6th.	Whole.
Alkali percentage ...	.21	.39	.48	.48	.47	.47	.42

In the clay soils the danger of a rise of alkali with over-irrigation is considerable, and to under-drain such compact soil would be very expensive. Not much damage has yet been done, but the scheme is only a few years old.

Slopes and Methods of Irrigating.

The general nature of the surface is gently undulating, the creeks —seldom more than five miles from one another—being separated by considerable rises. The longitudinal fall along the river and creeks is from 10 to 15 feet per mile, and the transverse slope is usually much greater, being as high as 100 feet or more per mile over much of the area. Apart from the river bench-lands the flattest area is in the bend round Indian Creek. Close to the river is a series of terraces, and the land adjoining the river is fairly level. With such steep transverse slopes terracing for basin-soakage irrigation would be too expensive, and most of the irrigation is by simple surface flow with little directing walls to cover high lumps, but often with no borders at the side or collecting furrows at the bottom. There is little to learn here as to methods of applying water.

Crops.

On over half of the area cereals are grown. Less than 20 per cent. is covered by lucerne. A large area is simply irrigated pasture, and the rest vegetables and miscellaneous crops.

Wheat yields about 17 bushels per acre—the market value being 70 cents per bushel. Lucerne gives at most three cuttings per year, with an average total of over 2 tons. It sells at about $5 per ton in stack, and $8 baled, f.o.r., but is mostly used for fattening stock.

Settlement and Cost.

The whole area proposed to be irrigated by the scheme is 98,000 acres, of which nearly half was privately owned before the inception of the scheme, and the remainder was unoccupied Federal ground.

Farm units in private ownership cannot exceed 160 acres per person, and on Government land the maximum farm unit is 80 acres, except within two miles of town sites, where the limit is reduced to 40 acres. The first Government lands were given out in 1908, and, by the end of 1912, 25,000 acres had been thrown open to settlement, of which about 4000 remained unoccupied. Of the privately owned ground only about 25,000 acres were covered by water-right contracts, so that a total of less than 50,000 acres was entitled to irrigation, and of this area only 28,000 acres were irrigated in 1912. The land has been settled more slowly than was anticipated, and a proportion of those who have taken out lands have done so as a speculation. This is especially the case near the town sites, where teachers, bankers, storekeepers, attorneys, and others are able to carry on their business while at the same time fulfilling the minimum conditions of the Reclamation Act as to residence and cultivation. Numbers of the private owners have not signed up, because they rely on a fair rainfall and seepage from surrounding irrigated plots. The storage dam cost nearly one and a quarter million dollars. The cost of the scheme up to date is about three and a quarter million dollars, which is considerably in excess of the estimate. This is about $33½ per acre of the entire proposed scheme, of which, however, barely half has yet been taken up. The building charge for the first lands given out was $30, but this has been raised with each new lot given out, the last charge being at $40 per acre. The annual operation and maintenance charge has also gone up gradually from $0.40 to $0.60 per acre. The actual cost was, however, in 1912 about $60,000, which was $0.9 per acre of the area then liable to charge, and about $1¼ per acre for the portion of the latter area already occupied or signed up.

It seems probable, therefore, that, when the scheme is completed and all lands are taken up, the building charge will be not much less than $45 per acre, especially if expensive drainage is found necessary, and the annual working charge will be about $1 per acre.

Distribution of Water.

Three watermasters, two gate-tenders, and eighteen ditch-riders are required to regulate the distribution of water over the present area (50,000 acres signed up, of which 28,000 acres were actually irrigated in the season).

The farmer, when he requires water, gives a couple of days' notice (on post-cards provided for the purpose) stating how many cusecs he requires, and for how many days. These are posted to ditch-riders or left in boxes at the head-gates of minors, where he collects them. From them he is able to frame an estimate in advance for the supply to come down each minor. This estimate he sends to the watermaster, who, from all the estimates, regulates the flow at the reservoir and at each distributary.

As larger areas become irrigated a system of rotation will be necessary in periods of greatest demand, and this is now being started.

The application in 1912 was 1.1 foot per acre at the fields, and about 60 per cent. more measured at the reservoir.

CHAPTER II

HUNTLEY SCHEME

(United States Reclamation Service, Montana)

Locality.

THIS scheme is in the State of Montana, which is one of the States bordering on Canada. It is in latitude 46 degrees north, and is the most northerly scheme I inspected in America.

The average altitude of the lands is about 2900 feet. It derives its water from the Yellowstone River, which runs in a north-easterly direction to join the Missouri River, and has its origin in the Yellowstone National Park region of the Rocky Mountains, where the Yellowstone Lake and the high surrounding mountains with peaks over 10,000 feet high give an abundant supply of water.

The range of temperature is from −35° F. to 100° F.

Rainfall and Water Supply.

The average rainfall over the irrigated area is about 12 inches, the heaviest fall being usually in spring and early summer. The irrigating season is from 1st May to 1st October.

The water supply in the river is more than sufficient for direct flow at all seasons, although considerable irrigation is carried on higher up the river. The flow at the head-works is seldom less than 3000 cusecs at the lowest periods in winter, and at its highest has reached 30,000 cusecs. The greatest flow is in summer, when the snow on the

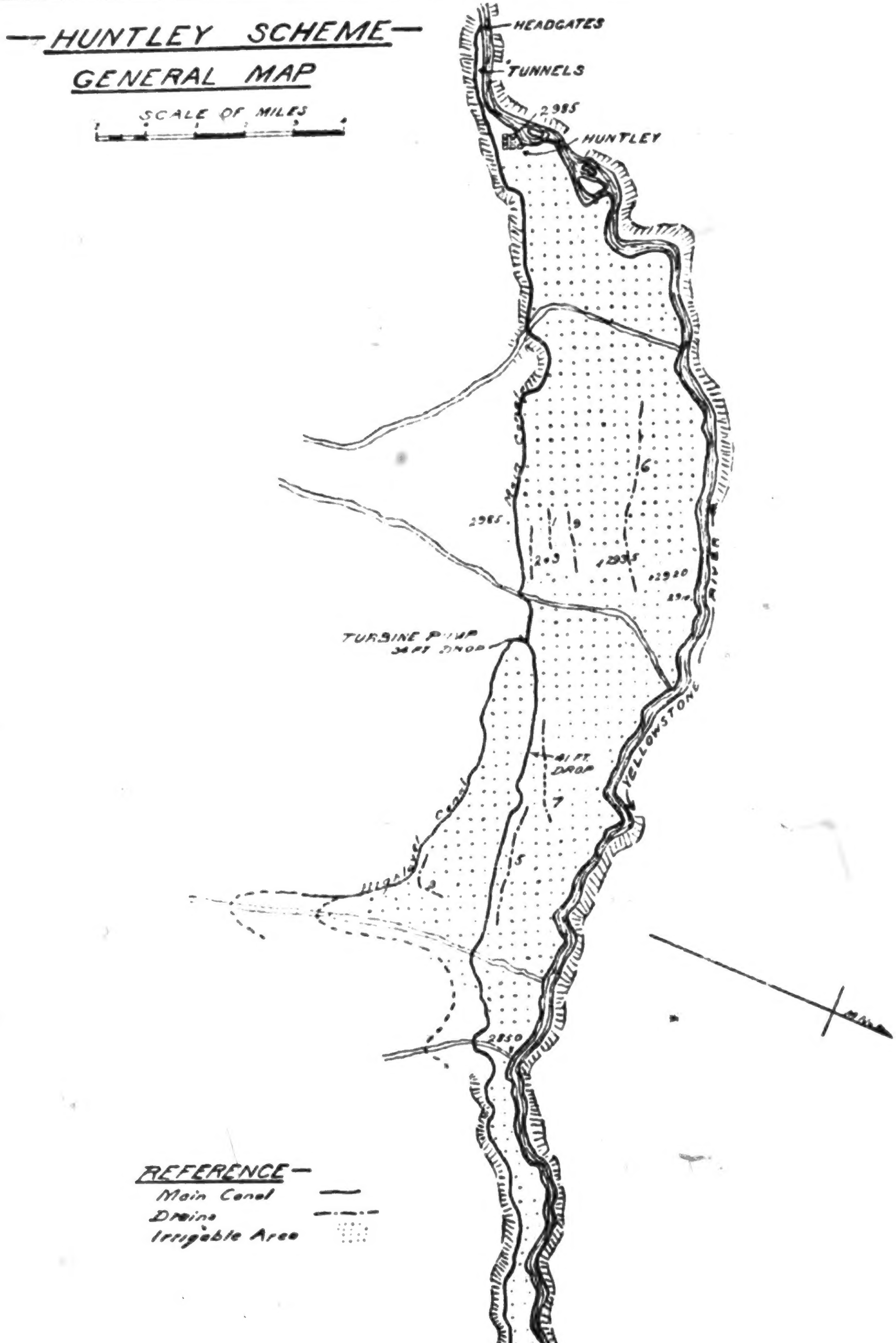

HUNTLEY SCHEME
GENERAL MAP
SCALE OF MILES
HEADGATES
TUNNELS
2985
HUNTLEY
Main Canal
6
2985
2935
2920
TURBINE PUMP
34 FT. DROP
41 FT. DROP
7
5
YELLOWSTONE RIVER
Highline Canal
2850
REFERENCE
Main Canal
Drains
Irrigable Area

Fig. 5.

mountains begins to melt, and the fluctuations are not so sudden as in a river depending on rainfall, the lake and melting snows giving a steadier flow.

As the whole area to be irrigated is only 32,000 acres, and the irrigating period is from 1st May to 1st October, when the river flow is greatest, it is obvious that storage is not necessary on this scheme.

Outline of Scheme.

The irrigable lands lie wholly on the right bank of the river, and stretch for about 30 miles along it, with a maximum width of about 3½ miles, but less than 1 mile wide in the bottom length.

The land forms a fairly level bench. Round the edge of it and on the other side of the river, a higher rocky bench extends.

The works consist of a main furrow 32 miles long, skirting the edge of the bench. About 14 miles below the head works the main furrow drops 34 feet, and continues high enough to command the lower bench. The drop is utilized to drive turbines and pumps which feed a furrow 45 feet higher, commanding about 5000 acres on the upper bench. The lower main canal again climbs into the slope of the bench at about 17 miles, and a second drop of 41 feet is given there to keep the canal in easier ground at the foot.

Works.

As the low-water flow is seldom below 3000 cusecs, even in winter, no weir is necessary at the intake, the sill of the intake gates being simply placed (at 2996) about 7 feet below low-water level in the river.

The waters being comparatively clean, there is no difficulty with silting at the head.

The head gates consist of two simple sliding steel gates, each 7 feet high by 5 feet wide, and worked by screw.

The first two miles of the furrow were somewhat difficult, as high rocky bluffs approach close to the edge of the river and the narrow low terrace of alluvium was already utilized by a railway line. Consequently the furrow had to run behind the railway and pierce the bluffs in three places with tunnels of a total length of 2650 feet. These tunnels are 9.2 feet wide by 9 feet high, the upper 3 feet being of circular section, and the whole of the inside lined with concrete from 6 inches to 1 foot thick. The slope of these tunnels is 1 in 1000, and the capacity with full supply (7 feet deep) is 400 cusecs. The main canal, after emerging from the bluffs, has a bed-width of

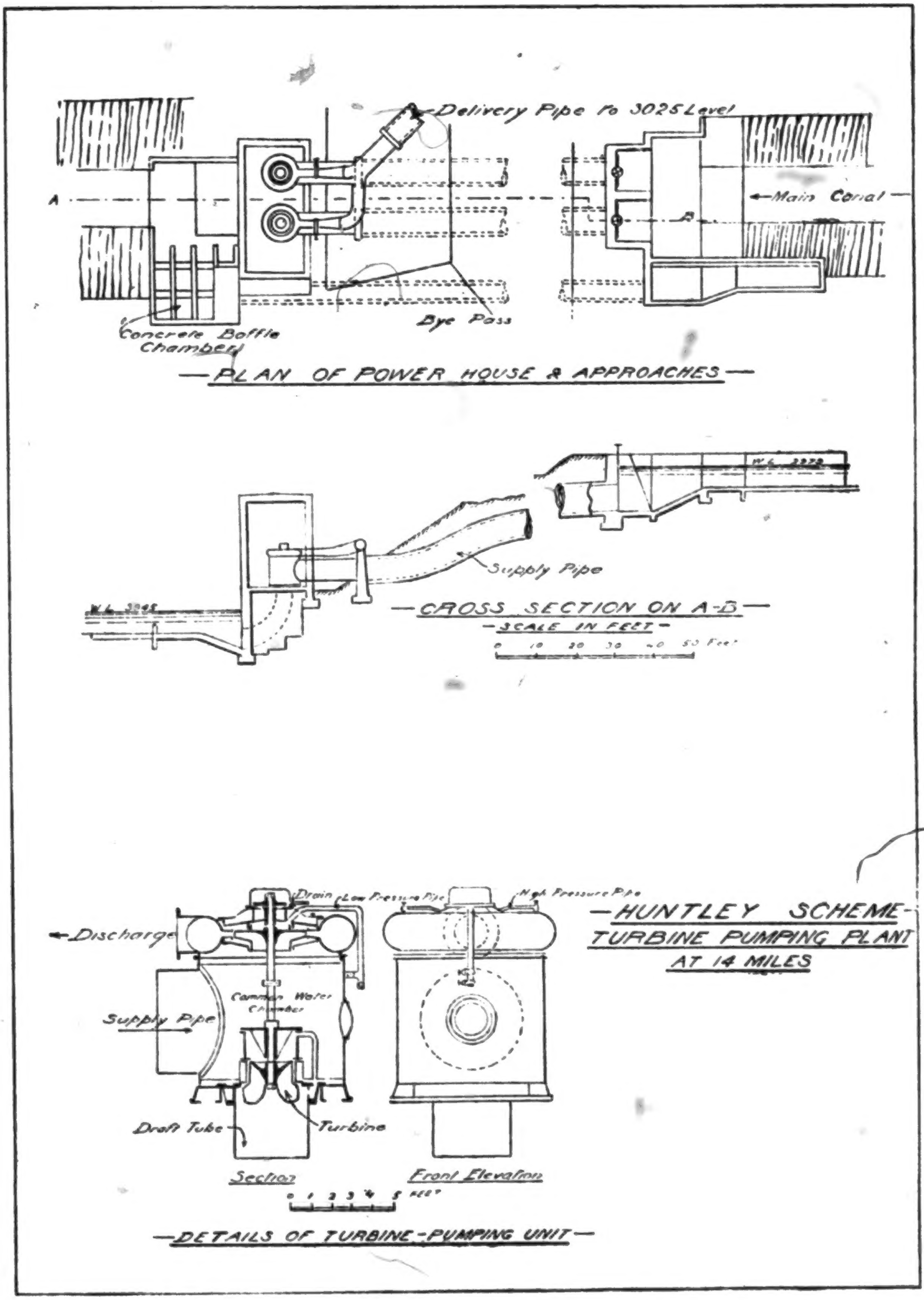

Delivery Pipe to 3025 Level
A
Main Canal
B
Concrete Baffle Chamber
Bye Pass
—PLAN OF POWER HOUSE & APPROACHES—
W.L. 2979
Supply Pipe
W.L. 2945
—CROSS SECTION ON A-B—
—SCALE IN FEET—
0 10 20 30 40 50 Feet
Drain
Low Pressure Pipe
High Pressure Pipe
Discharge
Common Water Chamber
Supply Pipe
Draft Tube
Turbine
Section
Front Elevation
0 1 2 3 4 5 FEET
—DETAILS OF TURBINE-PUMPING UNIT—
—HUNTLEY SCHEME—
TURBINE PUMPING PLANT
AT 14 MILES

Fig. 6.

14 feet, full-supply depth of 7 feet, slope of 1 in 4500, and capacity of 400 cusecs with 7 feet flow. The size diminishes as distributaries are taken out, and the slope increases to 1 in 1000 when the supply falls to 70 cusecs.

The most interesting structures are the drop and pumping plant at 14 miles and the pipe drop at 17 miles (see photos A and B, plate 2).

Hydraulic Pumping Plant of 286 h.p.

The details of this plant are given on page 22, fig. 6. The main feature is that both the turbine and pump are mounted on a common vertical axle and encased in a common supply chamber, the water passing inward and downward through the turbine and upward and outward through the pump. There are two of these units, each supplied by a separate pipe from the end of the canal, where gates and a bye-pass spillway are provided. Each supply pipe is 5 feet 2 inches in diameter and about 190 feet long. For the greater part it is of 9-inch reinforced concrete, the end connecting to the turbine being of riveted steel. The bye-pass is a 4-foot reinforced concrete pipe 220 feet long, ending below the power-house with baffles to check the velocity. There is a common delivery pipe for the two pumps. This is 4 feet diameter, 1385 feet long, and is of 9-inch reinforced concrete.

The common casing is 84 inches in diameter and about 10 feet high. The vertical axle is provided with a guide-bearing above the gate chamber of the turbine, and a combined guide and water-cushion bearing above the pump to take the weight and thrust. The latter consists of a plate at the top of the axle to take the water pressure when running, and the solid part of the impellor to take the pressure when starting. When the pump is discharging, the two small pipes shown in the front elevation supply pressure from the whirlpool chamber of the pump to the bottom side of the top bearing-plate of the axle. In starting, before the whirlpool pressure has reached its full value, the space above the solid part of the impellor is opened to the atmosphere by means of the pipe shown in the section, and the upward pressure of the supply water supports the axle. When full speed is obtained the opening of this pipe to the atmosphere is closed and its tap to the supply chamber is opened, thus equalizing the pressure on both sides of the solid part of the impellor, the upper plate being now supported by pressure from the whirlpool chamber.

The normal speed is 340 revolutions per minute, and the discharge of each pump is 28 cusecs, or a total of 56 cusecs, lifted 45 feet.

The full-supply discharge of the canal at the site is 240 cusecs, which is more than is needed for the turbine. The efficiency of the plant is 55 per cent. The complete cost of the plant and all structures in connection with it was about $51,000. Working costs are very low, as the plant is so simple and self-contained.

The other drop of 41 feet at 17 miles is on a gradual slope, and consequently a shoot or pipe was necessary. A 3 foot 3 inch diameter reinforced concrete pipe about 200 yards long was built with elaborate baffles at the end to check the velocity on entering the lower canal (see photo).

Soil, Slopes, and Drainage.

Drainage.

The soil consists of a sandy loam and heavy clay. A considerable area overlies gravel, but in pockets and not continuous. Seepage and alkali have appeared, and expensive drainage operations were being carried out at the time of my visit. Elaborate preliminary surveys of the water-table are carried out before locating the drain lines, test holes being made by means of post-hole augurs, from 100 to 200 yards apart over the whole area affected. Contour pipe drains are built, discharging into natural open drains. The location of some of these drains is roughly indicated on the general plan and the lengths are as folows:—

No.	1	2	3	4	5	6	7	8	9	10
Length	2500′	5500′	2080′	300′	8000′	19,300′	11,300′	5400′	4850′	23,000′

Total ... 82,230′ or 16 miles.

Of these the first five are finished, and the sixth, seventh, and tenth were in course of construction.

The clay is from 3 to 8 feet deep and overlies the gravel, and the drains are placed from 7 to 11 feet below the surface. The trench is excavated by means of large bucket-ladder trenching machines. One of these is an Austin 36-horsepower oil-driven machine (with caterpillar tread) which moves along in front of the trench, and, if the sides are self-supporting, leaves the trench almost ready for pipe laying. It can do up to 500 feet per day. Another similar machine, used by a contractor, was a Parsons steam-driven trencher. In many places the water is so strong through the gravel that the sides cave in unless timbered. For timbering trenches large numbers of adjustable steel struts with ball joint are used, which are much more easily inserted and removed than timber struts.

The trenching and pipe laying begin from the bottom. The grade is generally steeper than 1 in 1000, which is the flattest. The size of the pipes varies according to the estimated flow, and tapers from a smaller pipe at the top end to the biggest at the bottom of the line. One line started with a 10-inch pipe at a grade of 1 in 620, and ended with a 15-inch pipe at a grade of 1 in 770. Circular glazed earthenware pipes are used in 2-foot lengths with plain ends. The ends butt against each other and water enters through the bottom one-third of the joint, the upper two-thirds being covered with tarred felt strips 5 inches wide to keep sand from washing in.

The good effect of these drains is already being noticed in the rapid fall of well-levels and the drying out of seeped areas.

The cost of completed drains is probably not less than $1½ per foot.

Methods of Irrigating.

A few spot-levels are given on the plan to indicate the slope of the ground. The longitudinal fall along the river is about 6 feet per mile. The transverse slope from the canal to the river edge is about 18 feet per mile, but, as there is a series of benches with small drops from one to the other, the average slope on the irrigable parts is about 10 feet per mile. Irrigation is therefore very easy, and is usually done by surface flow down the slope between borders. On a large area, however, sugar beets are cultivated, and for this crop furrow irrigation is necessary.

Crops.

About 14,400 acres were cropped in 1912. Of this area about 35 per cent. is given to sugar beets, 30 per cent. to cereals, 25 per cent. to lucerne, and the rest to garden and miscellaneous products.

Lucerne gave in 1912 (a bad year) an average return of 2.6 tons per acre for three or fewer crops. Its average market value is $7 per ton. The most interesting crop is the sugar beet. This is very widely cultivated on all irrigation schemes within the neighbourhood of Billings, about 12 miles from Huntley, where there is a large sugar factory. The heavy soils are well suited to sugar growing, and, as a large area of the scheme is heavy clay and the returns from sugar beets are better than from cereals, the advantage of a neighbouring sugar factory is enormous. Nearly 200,000 tons of sugar beets are handled annually by this factory, producing some 30,000 tons of sugar, market price being about $110 per ton. There are at present nearly 5000 acres under beets on the Huntley scheme, producing on the average 10 tons per acre. The average price paid by the sugar company is about $6 per ton, depending on the tested sugar percentage. All handwork, such as thinning, hoeing, pulling, and topping, is usually done by contract for about $20 per acre with special labourers who come from the east for this purpose. The farmer does all ploughing and carting himself and provides accommodation. The sugar company has two specialists whose business it is to advise farmers as to methods of cultivation and fix up contracts with labourers. The two specimen contracts in the appendix to this chapter will indicate the nature of the work and payments. If the company has sufficient contracts in a certain area it erects at the nearest railway siding an elevated dumping platform, by which the contents of wagons are weighed and dumped into trucks below. The company pays railage up to about 40 miles, the cost being about 30 cents per ton up to this distance. The experts advise a few deep irrigations in preference to a larger number of shallow irrigations, so as to force the root down, the result being a higher proportion of sugar to pulp. A farmer should easily make an average net profit of $30 per acre out of beets. The possibilities of this crop are worth considering for South Africa.

Settlement and Cost.

The entire area contemplated by the completed scheme is about 32,000 acres, of which about 3200 were in private ownership at the inception of the scheme, the rest being originally Indian reserve land, but subsequently ceded to the Federal Government at a charge of $4 per acre. The first lands were given out for settlement in 1907, and about 26,000 acres have now been thrown open, of which 23,000 have been taken up by settlers.

The total area under water-right contracts, including private land, is about 24,000 acres. The scheme is developed sufficiently to supply water to 29,000 acres. The actual area irrigated in 1912 was 14,400 acres. The limiting size of a holding is 160 acres, but the average holding is less than half of this. The total building cost to date is $918,000. The building charge to settlers is $30, and a further $4 for Indian reserve fund.

The operation and maintenance charge was at first 60 cents per acre, but was raised to $1 in 1912. The actual cost in 1912 was $1, excluding betterments, which cost another $1 per acre capable of irrigation. Drainage works will send up the cost considerably.

There are fourteen schools already in the settlement, and a telephone connects most of the isolated homesteads. A "rural post" system is in force, each homestead having a box on a post at a convenient corner where collections and deliveries are made daily.

Distribution of Water and Duty.

Two superintendents and nine ditch-riders see to the distribution of water, which the user obtains after notification by post-card or telephone. As the greater part of the area is now taken up, and a large proportion already cultivated, it is natural that at periods of greatest demand the canal capacities are not sufficient to supply all users at once; and for this purpose, and also to reduce seepage as much as possible, a rotation system was started in 1912. At first a weekly rotation was worked out, but this met with such opposition that eventually a four-day rotation was adopted, half of each distributary being worked in alternate periods of four days.

Last year the application at the fields was approximately 1½ foot, and at the intake 3¼ feet, but about 1¼ foot of this was wasted water, chiefly because more had to be passed through the turbines than was required on the lands below.

APPENDIX.

SUGAR BEET CULTIVATION.

CONTRACT BETWEEN GROWER AND BILLINGS SUGAR COMPANY.

1. The grower agrees to prepare the land for, plant, block, thin, cultivate, irrigate, harvest, and deliver during the season of 1913, in compliance with directions of Billings Sugar Company as may be given from time to time, ... acres of sugar beets, but in no event shall the company be held liable in damages for any failure or partial failure or any injury or damage to beets.

2. The seed used shall be only that furnished by the company for either planting or replanting the acreage herein specified, for which the grower shall pay ten cents (10 c.) per pound, and not less than 20 pounds per acre shall be used, same to be paid for out of the proceeds of the first beets delivered.

3. The grower agrees that all beets grown by him will be harvested and delivered to the company as directed at the factory or in cars at designated receiving stations of the company, properly topped at base of bottom leaf, and that knives will not be used for lifting beets, but hooks may be used, provided they are properly driven into the top of the crown of the beet only. The grower further agrees that all beets grown and delivered by him shall be free from dirt, stones, trash, and foreign substance liable to interfere with the work at the factory, and shall be subject to proper deduction for tare, and that he will protect the beets from sun or frost after removal from the ground. The company has the option of rejecting

any diseased, frozen, or damaged beets, beets of less than eighty per cent. (80 %) purity, or beets that are not suitable for the manufacture of sugar. It being agreed and understood that the company shall not be obliged to receive any beets prior to 1st October containing less than fifteen per cent. (15 %) sugar. It also being understood that the company will commence receiving the crop as soon as the beets are thoroughly matured.

4. In the event that any portion of the beets grown under this contract (except that portion of the crop which is to be siloed as herein provided) shall not by the first day of October of said year be ordered delivered by the company, then in such case it shall be the duty of the grower to promptly commence and proceed with the harvesting and delivery of such beets as come within the contract requirements after the said first day of October without further notice from the company, and to fully complete delivery of all of said beets on or before the fifteenth day of November of said year.

5. The grower agrees to silo, if so directed in writing by the company prior to harvest, any portion of the tonnage produced on the above contracted acreage not to exceed twenty-five per cent. (25 %) of the entire crop grown hereunder.

6. Beets delivered and accepted will be paid for by the company as follows:—

Sugar %.	*Price per ton $.*
12 —14	5.00
14 —14.5	5.12½
14.5—15	5.25
15 —15.5	5.50
15.5—16	5.62½
16 —16.5	5.75
16.5—17	5.87½
17 —17.5	6.00
17.5—18	6.12½
18 —18.5	6.25
18.5—19	6.37½
19 —19.5	6.50

Add 12½ cents per ton additional for each one-half per cent. above 19.5 per cent.

For all beets siloed seventy-five cents (75 c.) per ton extra shall be paid, it being distinctly understood, however, that none of such siloed beets shall be delivered until the company sends written instructions to the grower to make delivery of "siloed beets," also that all of said siloed beets shall be ordered and delivered prior to 31st January.

Payments to be made as follows:—

On or about 1st October for beets delivered and received on or before 15th September.

On or about 1st November for beets delivered and received 16th September to 15th October, inclusive.

On or about 15th November for beets delivered and received 16th October to 31st October, inclusive.

On or about the 15th of each month thereafter for beets delivered and received during the previous calendar month.

7. The grower shall have the privilege of selecting, at his expense, a man of reliable character, satisfactory to the company, to check the tares and weights of the beets grown under this contract, at the receiving stations where such beets may be delivered, and to check in the tareroom laboratory the polarization of his beets.

8. It is further agreed, in the event of a shortage of cars after 1st October, and before freezing weather, causing serious delay to the grower, said grower shall be allowed to fork his beets into piles of not less than six feet depth, under directions of the company, at the receiving stations where large elevated dumps are established; and no loose dirt shall be removed from the wagon box until after having been weighed back. No wagons with holes or cracks in the bottom are to be used in the delivery of beets.

9. To ascertain the quality of said beets, the company shall have the privilege at various times during the growing and harvesting season of causing the beets to be sampled and polarized.

CONTRACT FOR HAND LABOUR.

Whereas the grower has entered into a contract with Billings Sugar Company for the growing of sugar beets, and is desirous of contracting with the contractor for doing the hand-work on said crop.

Now, therefore, the contractor agrees to receive as full compensation for said work the prices hereinafter specified, and the grower hereby agrees to pay said contractor for said hand-work as fast as the respective classes of work have been completed and approved by the agricultural superintendent or fieldman of Billings Sugar Company, less 10 per cent., which amount is to be reserved by the grower until the crop is harvested:—

	If 20 in. between rows.	If 18 in. between rows.
For bunching and thinning	$6.00 per acre	$6.60 per acre
For second hoeing	$2.50 ,,	$2.75 ,,
For third hoeing	$1.50 ,,	$1.65 ,,
For pulling and topping	$10.00 ,,	$11.00 ,,

The grower further agrees to provide reasonable living accommodations for the contractor without expense to him, and to furnish said contractor with water near at hand for drinking and domestic purposes without expense.

RULES AND REGULATIONS GOVERNING THE HAND-WORK ON THE ABOVE CONTRACT.

BUNCHING AND THINNING.

This work is to be commenced by the contractor just as soon as the beets show four leaves, and the grower has them cultivated, and must be completed as rapidly as possible in the following manner, to wit:—

Beets to be thinned from seven to ten inches apart, leaving only one plant in each place; no double beets shall be left. This work must be done so that the land will be entirely free from weeds.

SECOND HOEING.

This work must be commenced by the contractor as soon as the thinning is completed and the grower has finished the second cultivation by hoeing a little deeper than the first hoeing, killing and removing all weeds and removing any double plants that may have been overlooked in the thinning.

The grower must keep the crop cultivated so that at least ten inches of the centre of the row remains clear of all weeds and foul growth up to the time of third hoeing.

THIRD HOEING.

A third hoeing must be given the beets by the contractor, and in addition to such third hoeing any and all further hoeing necessary to keep the beets free from weeds until harvest of the beets is commenced must be done by the contractor; and in the event of the beets having grown so large that a third or fourth hoeing would injure them, then all weeds that grow up to the time of the commencement of harvest must be removed by hand, as the beets must be kept free from weeds at all times until harvested.

PULLING AND TOPPING.

This work must be done just as soon as the grower receives orders from Billings Sugar Company to dig his beets. The ploughing out will be done by the grower. The beets must be pulled by the contractor, and dirt knocked off by knocking the beets together as pulled and throwing them into piles. The ground on which the beets are to be piled must be cleaned off by the contractor and levelled down by the grower, so that the grower may fork the beets into the wagon free from dirt, rocks, leaves, or other trash.

The beets will be topped by the contractor in the following manner, to wit: By cutting off the tops squarely just below the crown at the base of the bottom leaf; *knives shall not be used for lifting beets, but hooks may be used, provided they are properly driven into the top of the crown of the beet only.*

All tools for the hand-work shall be furnished by the grower.

All cultivating, irrigating, ploughing out, and loading will be done by the grower, unless otherwise agreed upon.

All beets left in the field over night must be properly protected from frost by the contractor by covering the piles with beet tops, the tops to be removed by the grower before loading.

The grower reserves the right, in the event the hand-work is not done properly or with reasonable rapidity by the contractor that the crop would thereby suffer, to engage additional help for doing the work as cheaply as practicable under existing conditions, and to deduct the expense of the same from this contract; it being agreed and understood, however, that in the event of any dispute arising between the grower and contractor as to the interpretation of the above rules, as to the manner in which the work is being done, or as to the necessity of additional help, the agricultural superintendent or fieldman of Billings Sugar Company shall act as referee, and his decision shall be final and binding on both the contractor and grower.

CHAPTER III

SHOSHONE SCHEME

(United States Reclamation Service, Wyoming)

Locality.

THIS scheme is situated in the north-east corner of the State of Wyoming. The irrigable lands are at an elevation of 4000 feet to 5000 feet, and immediately east of them is the Yellowstone National Park in the Rocky Mountain range with peaks nearly 11,000 feet high. The Shoshone River rises in this region and runs eastwards through the irrigated area to join the Big Horn River which flows north and ends a little below Huntley in the Yellowstone River, a tributary, as we have seen, of the Missouri. It is interesting to note that three enormous drainage areas have their common meeting point in this neighbourhood. The Missouri and its tributaries, the Yellowstone and North Platte, originate here and run into the Mississippi, which discharges into the Gulf of Mexico; the Green River, a tributary of the Colorado, has a source here and eventually discharges into the Gulf of California; and the Snake River, running west to the Pacific, has its headwaters in this region.

The Shoshone scheme is on the western edge of the Big Horn Basin, which is a wonderfully interesting geological formation. A section through the basin north-easterly from Shoshone shows the more level hollow of the basin to consist of a single huge anticlinal fold about forty miles wide, bordered by two synclinal mountain ranges rising many thousand feet above the valley. Just west of the Shoshone scheme the huge synclinal fold of the Rocky Mountains begins, representing the upheaval of the great western mountains. The underlying formation is a massive granite which has been raised several thousand feet and is exposed in a short reach of the Shoshone canyon, just at the contraction where the Shoshone dam is built on the excellent foundation which the granite affords. Numerous dolerite dykes pierce this granite, just as in the granite in the Cape Peninsula, and one of these is very conspicuous at the dam site. Overlying the granite is the Cambrian system, followed by a large sequence of formations, exposed within a short distance in the Shoshone canyon on account of the steep easterly dip, and terminating in a Tertiary formation which covers the greater area of the hollow of the basin and overlies a considerable thickness of Cretacious beds. The Tertiary covering consists of alternating layers of soft sandstone in thick layers and clay with occasional boulder beds, all generally highly coloured of a grey or rusty hue. Much of this is covered, especially near the Shoshone scheme between the canyon and the irrigable lands, with a more recent series of extensive river terraces. Some of these are two miles wide and consist of coarse gravel and boulders with a shallow covering of sand or silt.

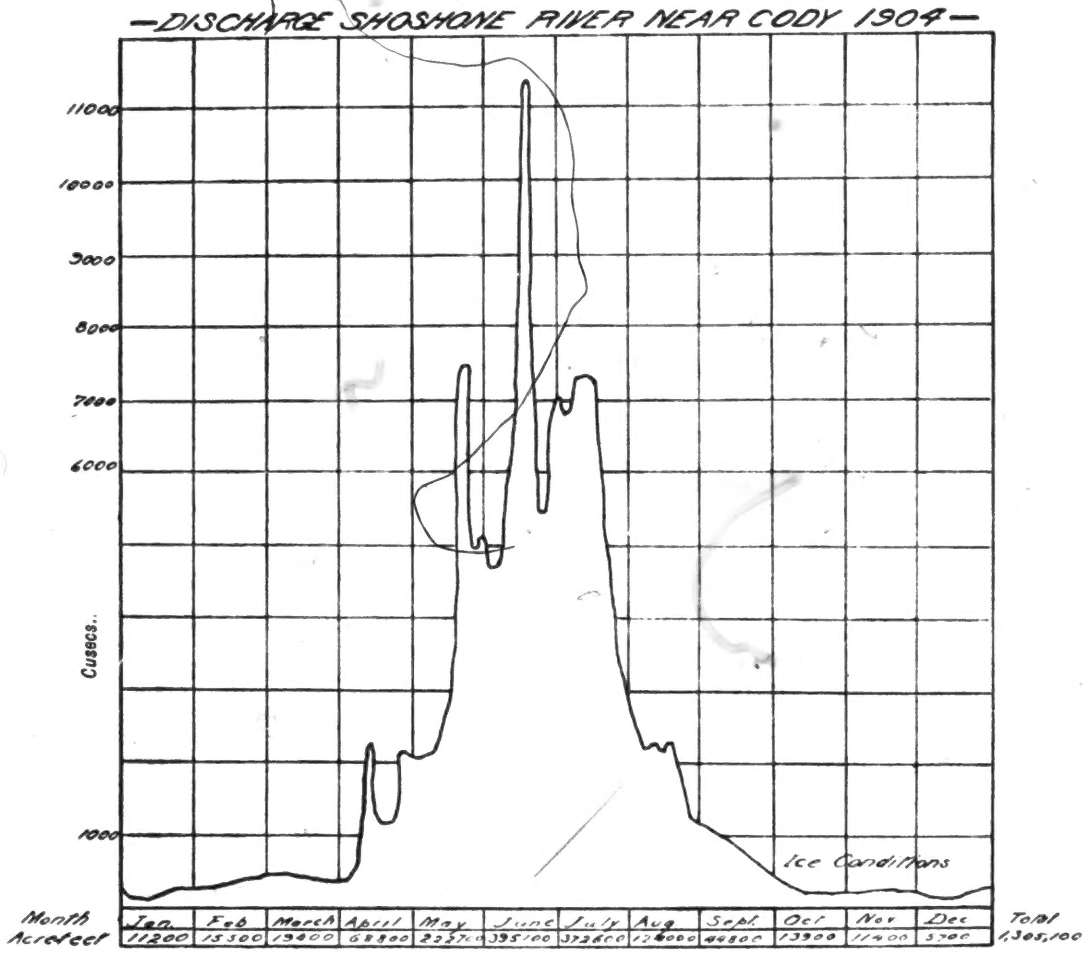
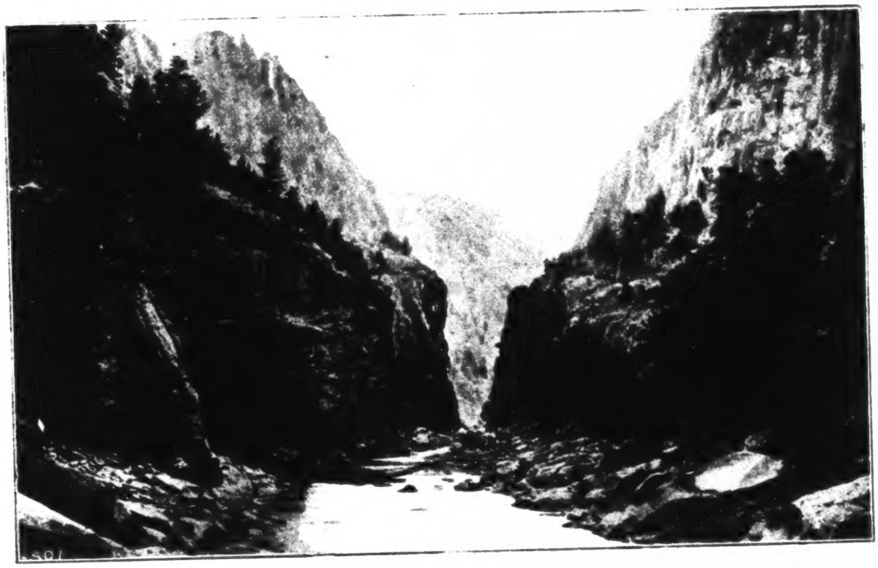


Fig. 7.

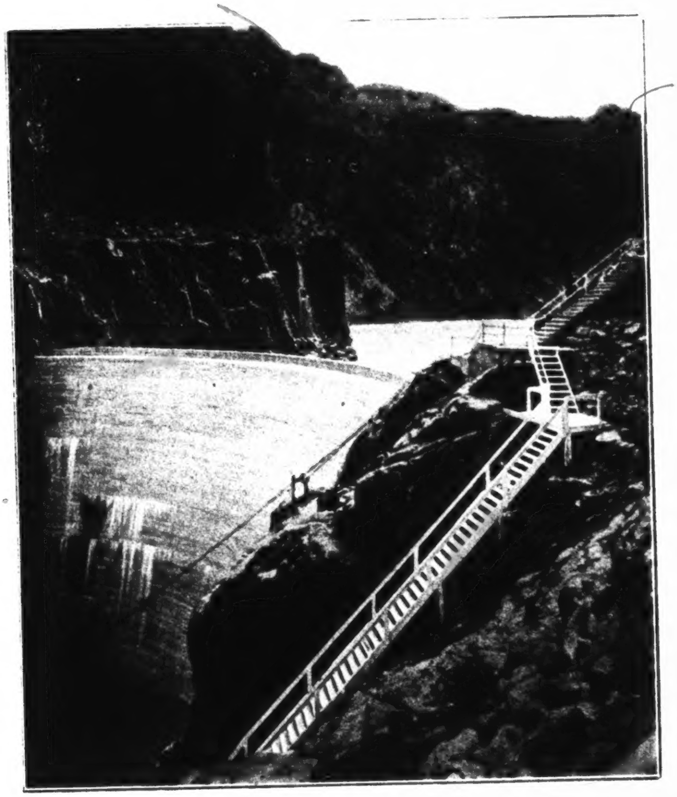
Irrigation is widely practised throughout the basin and the Shoshone scheme is one of the biggest.

The temperature varies from −31° F. to 101° F., and the irrigating season lasts from about 1st May to 1st October. Sudden changes of temperature are very common, and during my visit in September I experienced a change from fairly hot weather to a cold snowstorm.

SHOSHONE SCHEME.



(*a*) Dam Site before construction looking up stream.



(*b*) Completed Dam.

Plate 3.

SHOSHONE SCHEME.

(*c*) Completed Dam and Spillway.

(*d*) Foundation-rock for Dam.

Rainfall and Water Supply.

The drainage area above the storage dam is 1480 square miles, and the river derives most of its water from melting snow, the rainfall over the irrigable area being only about 6 inches.

The mean yearly run-off of the river is 1,125,000 acre-feet, the maximum being 1,420,000 and the minimum 905,000.

The average monthly flow would be as follows:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Percentage of annual flow...	2	1	2	4	15	29	27	9	4	3	2	2

The maximum observed flow is 17,000 cusecs.

Fig. 7 shows an actual discharge curve for 1904, which is rather above the average.

The whole area which it is proposed to irrigate by this scheme is 164,000 acres, though works have actually been constructed for only 42,000 acres, of which barely 22,000 acres have been taken up. The need for storage at present is therefore not very obvious, but, for the whole contemplated area storage will be necessary, especially as other older appropriations exist along the river. A reservoir has already been built capable of holding 456,000 acre-feet, but it has not yet been found necessary to draw on it extensively.

Outline of Scheme.

The main features of the scheme are shown on fig. 8. A large storage dam has been constructed in a narrow contraction at the head of the Shoshone canyon. A high-line canal is proposed for the north bank, starting from the storage dam and running at first for several miles in tunnel through the steep side of the canyon. This canal has not yet been constructed, and at present the water from the storage dam flows down in the bed of the river for sixteen miles to the Corbett diversion weir. This weir picks up the water again for the north bank canal under which all irrigation is at present being done. It is proposed to construct another diversion weir in the river about five miles below the Corbett weir to irrigate the lands on the south bank, but no part of this scheme has yet been built.

The Corbett diversion weir and tunnel were completed in 1907 and irrigation commenced in 1908. The Shoshone storage dam was completed in 1910. At present the scheme is only capable of irrigating 42,000 acres.

Engineering Works.

Storage Dam.

This dam was, at the time of its construction, the highest dam in the world, and, although it will be surpassed in height by others, such as the Arrowrock dam now in course of construction, it is the

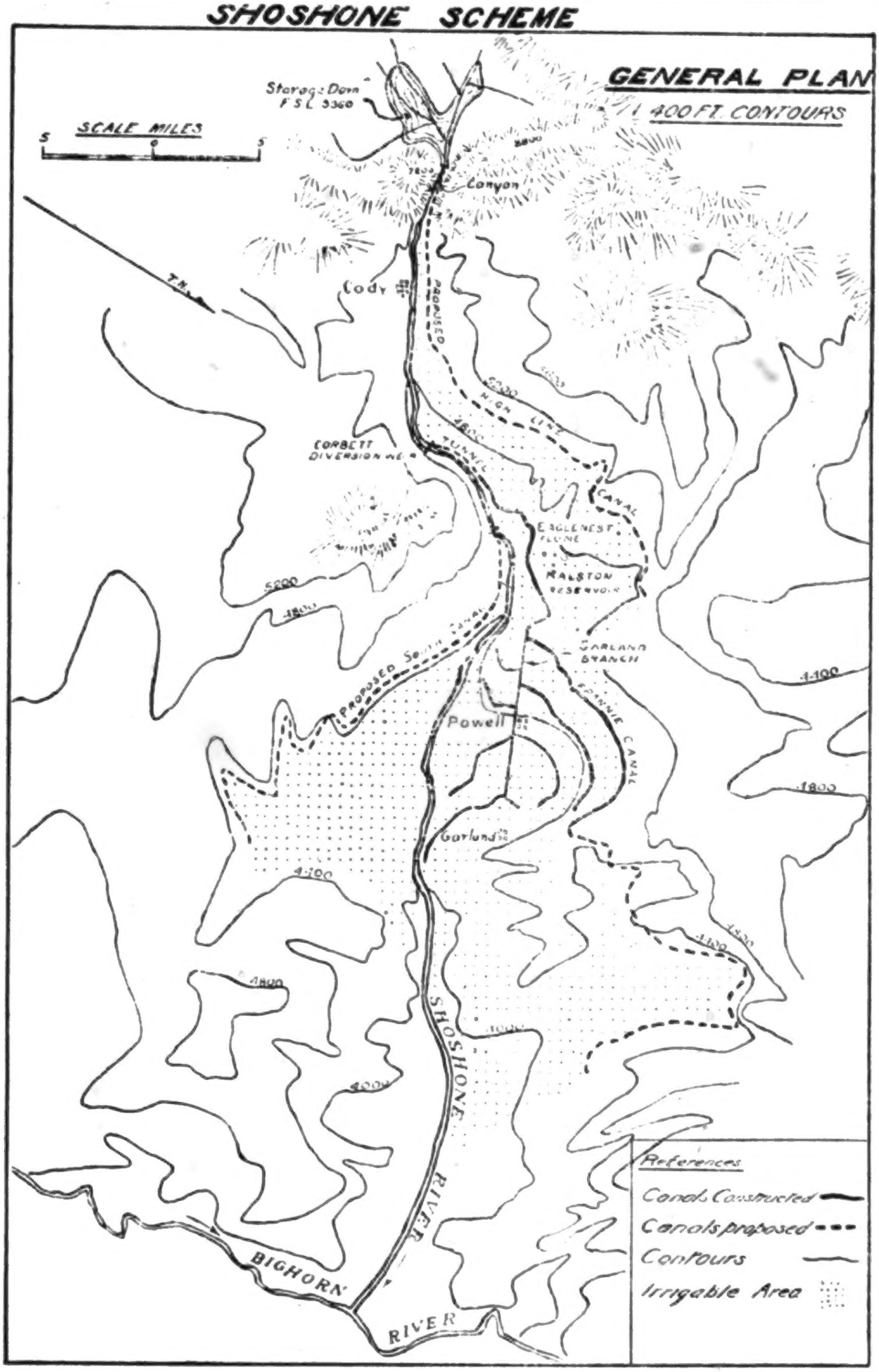

SHOSHONE SCHEME
GENERAL PLAN
400 FT. CONTOURS
SCALE MILES
5
0
5
Storage Dam
F.S.L. 5360
Canyon
Cody
PROPOSED
5200
HIGH LINE CANAL
4800
CORBETT DIVERSION WE.
TUNNEL
EAGLENEST FLUME
RALSTON RESERVOIR
5200
4800
GARLAND BRANCH
FRANNIE CANAL
PROPOSED South CANAL
Powell
4400
4800
Garland
4400
4800
4400
4000
4000
SHOSHONE RIVER
BIGHORN RIVER
References
Canals Constructed
Canals proposed
Contours
Irrigable Area

Fig. 8.

only dam of this height which has a greater height than length of crest. The height of the crest above the lowest point of the foundations is 325 feet and the parapet is 3 feet higher. The bottom 82 feet of the above height is through the gravel and loose boulders overlying the solid rock, and the height of the crest above the original bed of the river is 243 feet. The width of the canyon at crest-level was 180 feet, and at the bed of the river 70 feet. Not only is the section of the site favourable, but also the foundation rock is the excellent granite which underlies the great syncline, and is, fortunately, here exposed. Moreover, the storage area is fairly good, as the canyon opens out a short distance above the dam and the stored waters can extend eight miles up two branches of the river which join here.

The storage capacity is 456,000 acre-feet and 6600 acres are submerged.

Advantage was taken of the narrowness of the site to economize in the cross-section of the dam by making the centre line curved to a radius of 150 feet. The maximum cross-section is shown on fig. 9. The top-width is 10 feet, and the faces have uniform slopes of 6⅜ on 1 and 4 on 1 up and down stream respectively, to a depth of 245 feet, where the width is 108 feet. This width continues, with the exception of small footing projections, to the foundations.

This section is very much lighter than a simple gravity section, from which it also differs in the comparatively great slope of the up-stream face. The dam depends for its stability on arch action, and, if this be neglected, the line of pressure when the reservoir is full would fall well outside the base of the dam.

One of the chief considerations in the design of such an arch-dam is the effect of changes of temperature which are greater in the upper, thinner, and more exposed portion of the dam than in the lower portions, which are more often covered with water, more massive, and narrower. An increase of temperature (above that at time of building) causes the centre of the arch in the upper portion to move up-stream more than in the lower part, and, unless the section is properly designed, this unequal movement is liable to cause greater stresses in the masonry than can be caused by the water pressure. It is claimed that the great batter of the up-stream face and the uniform batter of both faces minimize the stresses due to this cause, and Mr. Wisner, who was consulting engineer for this dam, states that where a canyon is sufficiently narrow to allow of a dam "with a radius of 200 feet or less, the batter of the up-stream face should be at least one-half that

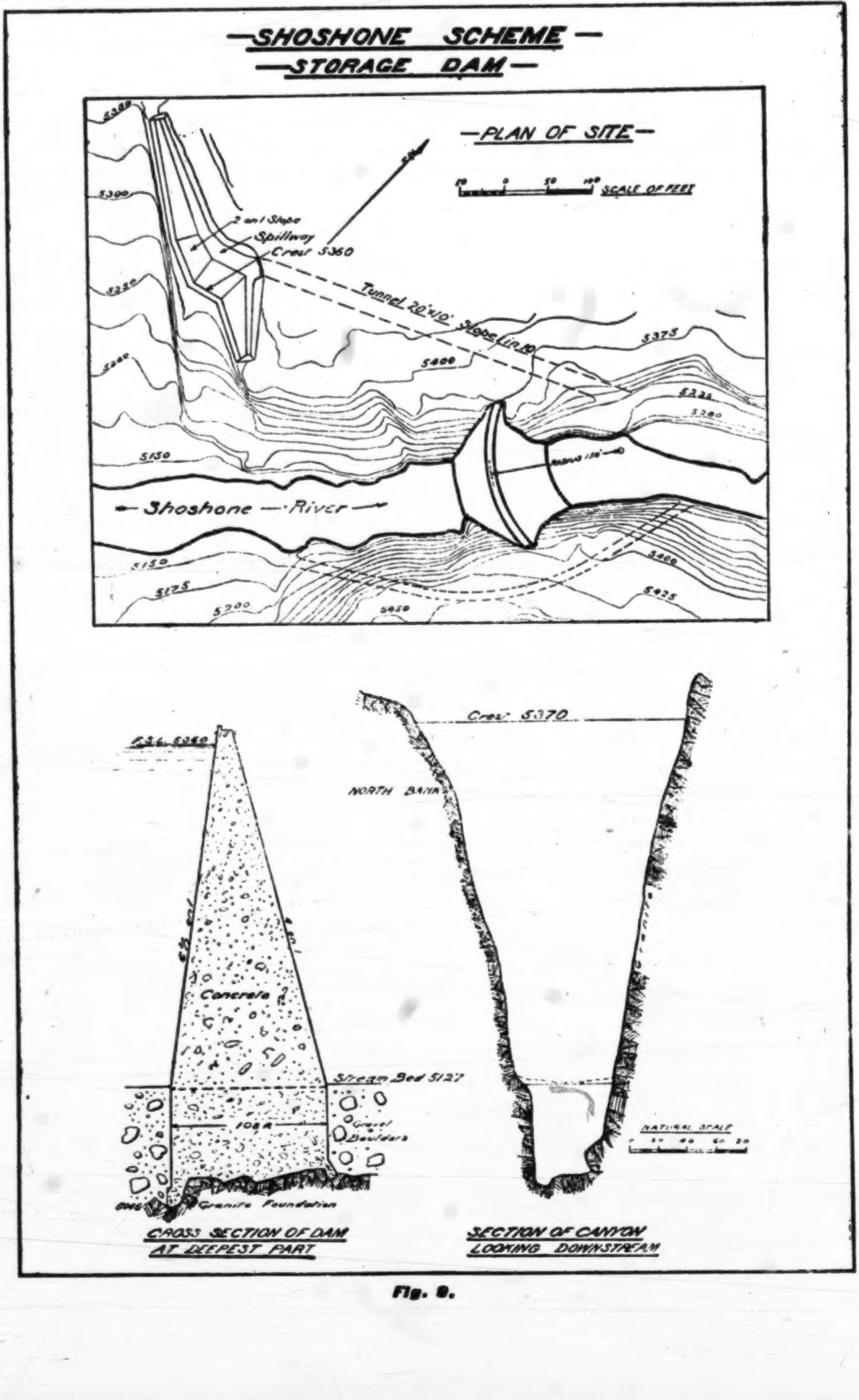

—SHOSHONE SCHEME—
—STORAGE DAM—
—PLAN OF SITE—
SCALE OF FEET
50
0
50
100
2 on 1 Slope
Spillway
Crest 5360
Tunnel 20'x10' Slope 1 in 10
5380
5300
5250
5200
5150
5400
5375
5225
5200
Radius 150'
Shoshone River
5150
5175
5200
5450
5400
5425
F.S.L. 5360
Concrete
Stream Bed 5127
108 ft.
Gravel
Boulders
Granite Foundation
CROSS SECTION OF DAM
AT DEEPEST PART
Crest 5370
NORTH BANK
NATURAL SCALE
SECTION OF CANYON
LOOKING DOWNSTREAM

Fig. 8.

of the down-stream face," and in dams of very short span both faces should have the same batter, and vertical reinforcement should be placed in the down-stream face and horizontal reinforcement in the up-stream face of the top portion of the dam to prevent cracking due to changes of temperature.

The concrete was 1 : 2½ : 5, and 25 per cent of "plums" were placed in it. The contents of the dam are 75,000 cubic yards.

The spillway is unique. There being no natural neck or ledge, a tunnel 405 feet long and 20 feet by 20 feet at a slope of 1 in 10 was cut through the granite of the left bank; the surplus water discharges into it over a weir perched on the cliff at the entrance, with crest 300 feet long and 10 feet below the dam crest.

The main outlet is a 10-foot by 10-foot concrete-lined tunnel, 500 feet long, through the granite on the right bank. The sill at the entrance is 230 feet below the crest of the dam, and the tunnel has a slope of 1 in 200. Near the discharge end are placed three high-pressure cast-iron gates, each 7½ feet high by 3 feet 8 inches wide. The operating mechanism is placed in a chamber excavated in the rock immediately above the gates, and consists of a piston attached to each gate and worked by oil pressure obtained by means of a pump driven by a dynamo and oil engine.

Another outlet tunnel has been made through the granite at 120 feet below the crest, and two cast-iron pipes, 42 inches and 15 inches diameter, were built through the dam at about 230 feet below the crest.

The preparation of diversion works and foundations took two years, and the placing of the concrete another two years.

Considerable difficulty was experienced on account of flood and failure of contractors. The storage dam and all sluices, tunnels, etc., have cost $1,195,000, including $214,000 for the purchase of submerged lands.

Corbett Diversion Weir.

This is a reinforced concrete pick-up weir, 400 feet long, across the Shoshone River, sixteen miles below the storage dam. The bed of the river consists of about 5 feet of sand, gravel, and boulders, resting on shale or clay. The crest of the weir is about 14 feet above the bed in the centre of the channel (see fig. 10).

The weir consists essentially of a 2-foot 6-inch thick reinforced concrete deck at a slope of 45 degrees, resting on a cut-off wall extending 3 feet into the shale and supported by buttresses 2 feet thick

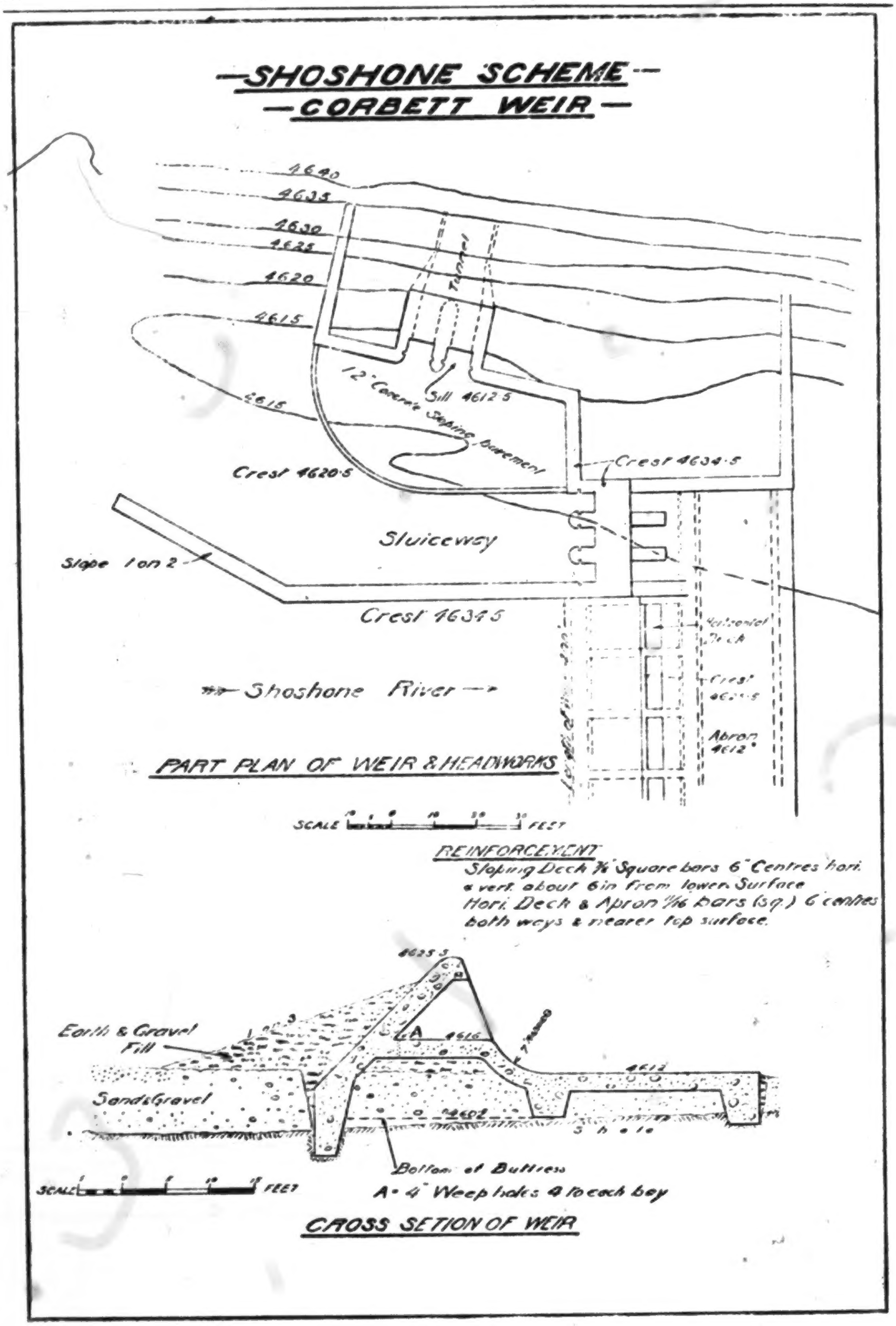

—SHOSHONE SCHEME—
—CORBETT WEIR—
4640
4635
4630
4625
4620
4615
4615
Tunnel
Sill 4612·5
12" Concrete Sloping pavement
Crest 4620·5
Crest 4634·5
Sluiceway
Slope 1 on 2
Crest 4634·5
Horizontal Deck
Crest 4625·5
Apron 4612
Shoshone River
PART PLAN OF WEIR & HEADWORKS
SCALE 0 10 20 30 FEET
REINFORCEMENT
Sloping Deck ⅞" Square bars 6" Centres hori. & vert. about 6in from lower Surface
Hori. Deck & Apron 11/16 bars (sq.) 6" centres both ways & nearer top surface.
4625·5
Earth & Gravel Fill
Sand & Gravel
4616
4612
4602
Shale
A
Bottom of Buttress
A = 4" Weep holes 4 to each bay
SCALE FEET
CROSS SETION OF WEIR

Fig. 10.

at intervals of 14 feet, having a back slope of 2½ on 1. A horizontal deck, 2 feet thick (with weep-holes) rests on the gravel bed at 9½ feet below the crest, extending from the back of the sloping deck to the back edge of the buttress; it then drops 4 feet in a circular curve and continues as an apron for 24 feet, resting on the bed with two cut-off walls down to the shale. The up-stream face up to 3 feet from the crest is filled with a mixture of earth and gravel at a slope of 1 on 3.

At the left end are three scouring gates 4 feet by 5 feet, with sills 13 feet below weir-crest, separated from the weir by a training wall 9 feet above weir-crest. On the other side of the scouring sluices is a curved weir with crest 5 feet below the weir-crest; the supply to the tunnel head-gates passes over this weir and down a smooth paved slope to the sill of the tunnel gates, which is 13 feet below the main weir-crest. The cost of the diversion weir was nearly $100,000.

Canals.

The main canal starts from Corbett weir in a tunnel 3¼ miles long. It is about 11 feet square and has a slope of about 1 in 700. It is mostly through sandstone, with some shale and clay, and is lined with concrete. The tunnel cost nearly $1,170,000. At the end of the tunnel is a settling basin with spillway and scouring tunnel and regulating gates across the canal. From this point the canal runs for seven miles to Ralston reservoir in open cutting for the greater part 40 feet wide on bottom, 6.5 feet full-supply depth, 1 on 2 side slopes, and 1 in 4500 longitudinal slope, though in rock and deep cutting the channel is narrower, steeper, and deeper. The full supply capacity is 1000 cusecs. About half-way along this length the Eaglenest Creek is crossed in an interesting reinforced concrete aqueduct, which at the same time acts as a regulator and escape. The waters of the creek pass under the aqueduct through eight openings, each 6 feet wide by 8 feet high. The walls between are 10 inches thick and support the floor of the aqueduct, which is 54 feet wide and 12 inches thick. The sides of the aqueduct between the piers consist of flashboards, over which the excess canal water can drop on to the extended concrete floor of the culvert below. Flashboard regulation is also provided across the canal at the end of the aqueduct.

The Ralston reservoir provides a means of regulation nearer the lands. It is an earth dam 700 yards long, with a maximum height of 40 feet, has an available capacity of 2100 acre-feet, and covers an area of 200 acres.

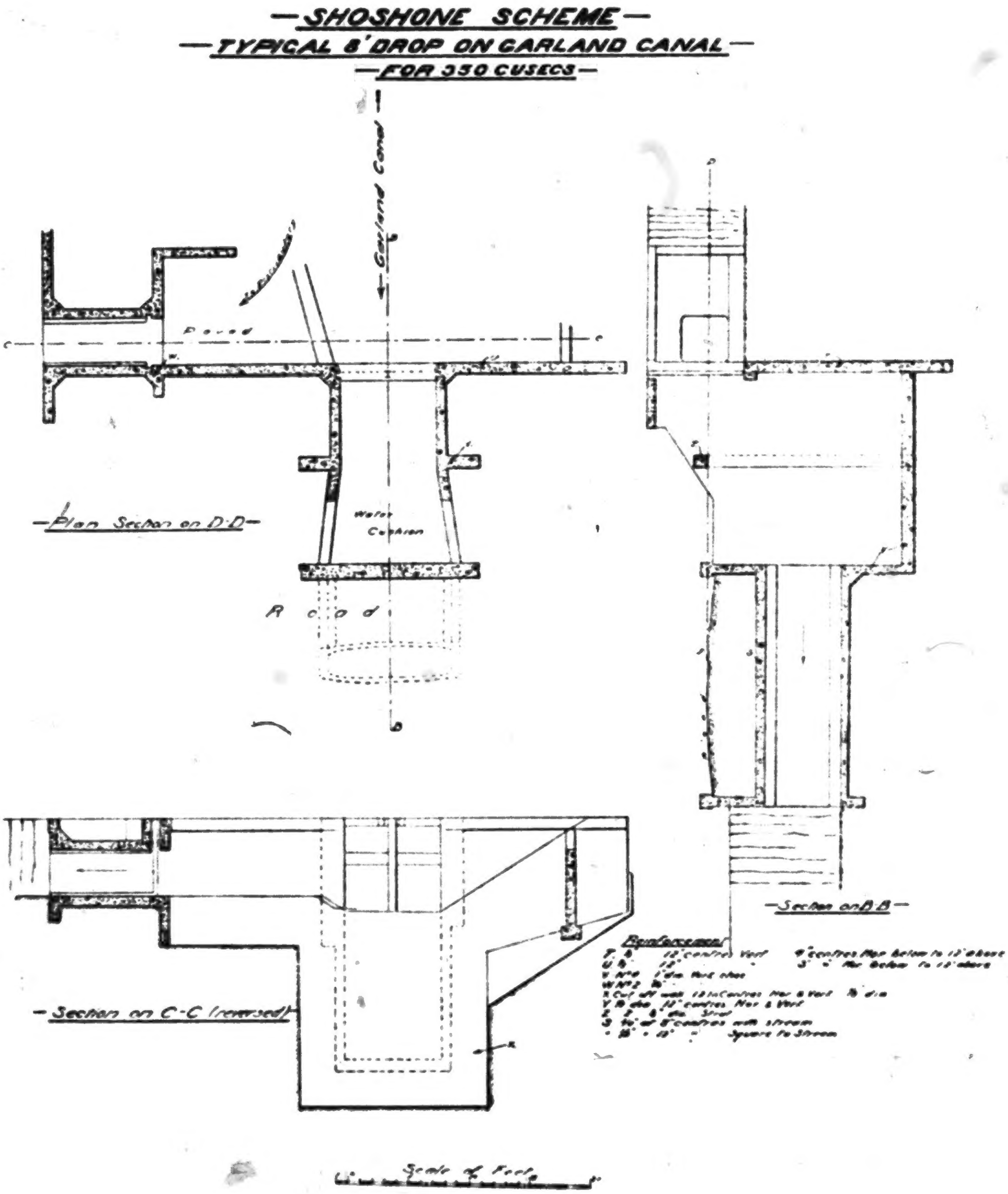

—SHOSHONE SCHEME—
—TYPICAL 8' DROP ON GARLAND CANAL—
—FOR 350 CUSECS—
Garland Canal
Road
—Plan Section on D-D—
Water Cushion
Road
—Section on B-B—
—Section on C-C (reversed)—
Reinforcement
T. & 12" centres Vert
9" centres Hor below to 12" above
U. & 12"
3" " Hor below to 12" above
X Cut off wall 12 in Centres Hor & Vert
Y 12" centres Hor & Vert
8" centres with stream
Square to Stream
Scale of Feet

Fig. 11.

From Ralston reservoir the main canal continues for 4 miles to the head of the Frannie canal. The canal in this reach is 40 feet wide and 6 feet deep, and has a slope of 1 in 4000. In this length the canal drops 50 feet in 2800 feet in a wooden shoot on the side of a hill, and also has five vertical drops each of 6 feet. From the head of the Frannie canal the Garland canal runs straight down the slope, and distributaries run out from it on both sides along the contours. The Garland branch begins 20 feet wide on bottom with 1 on 1¼ side slopes, 4 feet 9 inches full-supply depth, longitudinal slope 1 in 2500, and capacity 358 cusecs. As the laterals take off, the canal diminishes in size, and the slope becomes as steep as 1 in 1666. As the slope of the country along the Garland canal is about 27 feet per mile, or about 1 in 200, it is obvious that a large number of drops are required in this branch, and a vertical drop of from 6 to 10 feet is given at nearly every quarter-mile, the distributaries taking out just above a drop. Details of an 8-foot drop, where the capacity is 358 cusecs, are given on fig. 11. A bridge crosses the channel here and forms part of the structure. It will be noticed that a water-cushion is provided, but it seems that this type of structure is too cramped at the lower end, wave action and excessive velocity causing considerable scouring in the canal below, and the protecting pitching of the slopes has to be renewed constantly.

The distributaries which take out from the Garland canal usually follow the contours at slopes varying from 1 in 1000 to 1 in 666, and consequently fewer drops are required.

The minors taking out from them run down the slope again and require drops. The smaller drops are either vertical or through pipes. Types are shown on fig. 12. The Frannie canal starts with a bed-width of 29 feet, full-supply depth 4 feet 9 inches, side slopes 1 on 2, longitudinal slope 1 in 2800, and capacity 500 cusecs. As it follows the contour, no drops are required. This canal is constructed for only twelve miles and will be extended at a later date. As it now irrigates a much smaller area than it is designed for, a flow much below its full capacity is required, and, consequently, to head up the water and give the minors and direct outlets full supply, it has been found necessary to build a number of temporary wooden checks at intervals. A typical outlet from the canal is shown at the bottom of fig. 12. It will be noticed that in all the drops and outlets a little weir or obstruction is built on the discharge-end across the channel to retard the velocity and prevent scouring.

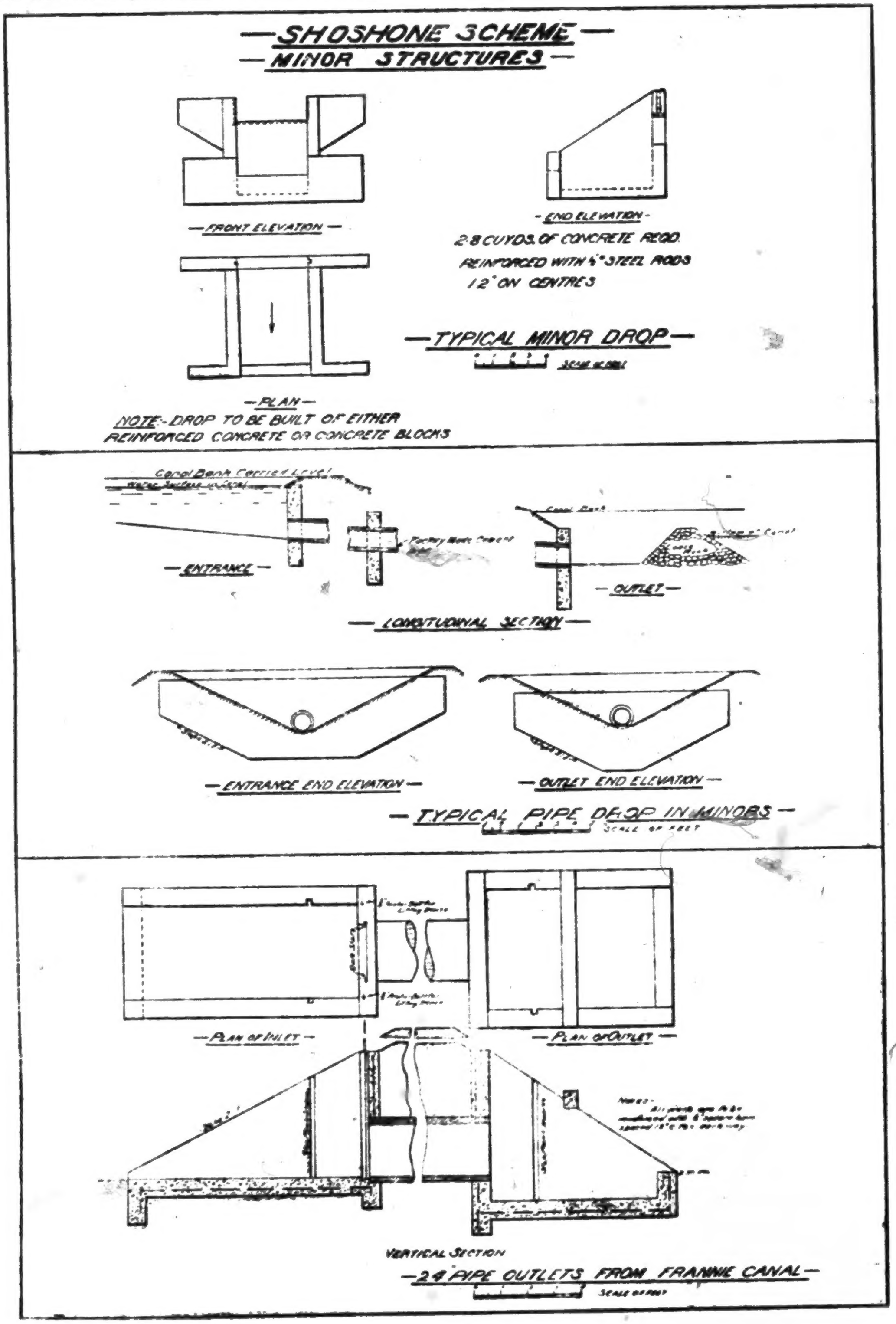

—SHOSHONE SCHEME—
—MINOR STRUCTURES—
—FRONT ELEVATION—
—END ELEVATION—
2.8 CU.YDS. OF CONCRETE REQD.
REINFORCED WITH ½" STEEL RODS
12" ON CENTRES
—TYPICAL MINOR DROP—
SCALE OF FEET
—PLAN—
NOTE:- DROP TO BE BUILT OF EITHER
REINFORCED CONCRETE OR CONCRETE BLOCKS
Canal Bank Carried Level
Water Surface in Canal
Factory Made Cement
—ENTRANCE—
Canal Bank
—OUTLET—
—LONGITUDINAL SECTION—
—ENTRANCE END ELEVATION—
—OUTLET END ELEVATION—
—TYPICAL PIPE DROP IN MINORS—
SCALE OF FEET
—PLAN OF INLET—
—PLAN OF OUTLET—
Notes:-
VERTICAL SECTION
—24" PIPE OUTLETS FROM FRANNIE CANAL—
SCALE OF FEET

Fig. 19.

Soils, Slopes, and Drainage.

The prevailing soil is a slightly sandy clay loam. For the greater part of the area at present irrigated it rests on sand and gravel, and has an average depth of 3½ feet and sometimes 1 foot or less.

Drainage.

The slope of the river through the irrigable area is about 27 feet per mile. The flat where irrigation is now practised has a slope of 27 feet and more per mile, generally parallel to the river, and is over 100 feet above the river bed. The water table, before irrigation was commenced, was about 20 feet below the surface.

With such a porous sub-soil, steep surface slope, high elevation above the river, and low water table, few people would have predicted that any trouble would arise from seepage or alkali, and yet, within four years of the opening of the scheme, the water table has risen 10 feet and a considerable area has been rendered unfit for cultivation by seepage and rise of alkali, which has made expensive drainage works necessary. Fig. 13, page 45, shows the position of the drains constructed or in course of construction in 1913. The plan adopted is to construct the drains down the steepest slope and not as intercepting drains along contours.

The first drains constructed (A, F, E, C, and H lines) were open cuts, but the later drains are all covered pipe-lines. Elaborate observations are made as to underground water level and depth of gravel before the drain-lines are located, and then careful sections are taken with augurs and test holes along the designed lines before work is commenced. The pipes are plain-ended, from 10 inches to 18 inches diameter, and they are laid in short lengths with open joints, as at Huntley. Practically all are at a depth of 8 feet below the surface. The longest end in Bitter Creek, and run parallel, about three-quarters of a mile apart, and square to the contours.

The average fall is about 1 in 200, the flattest slope being 1 in 400 and the steepest 1 in 170. All run, for most of the way, in the gravel and sand underlying the clay. Trap-boxes, 4 feet square, are provided at every 1000 feet.

The lengths and diameters of the drains are roughly as follows:—

Drain.	Length (feet).	Diameter.
K_1	13,100	10" and 12"
K	26,300	10", 12", and 15"
J	25,000	—
I_3, I_2, I_1 and I	52,100	10", 12", 15", and 18"
L	16,000	—
Total ...	132,500 feet, or 25 miles length of covered pipe drains in 1913.	

The total length of open drains is about 7½ miles. The board of experts has recommended the construction of a further 9½ miles of covered drains.

Trenching machinery for the excavation for the pipe-line is of two kinds. An Austin 40-horsepower trencher (with buckets), similar to that employed at Huntley, is used and does excellent work, except in running sand. As much as 1060 feet has been done in sixteen hours in favourable soil. The other type is the dragline excavator, with 1 cubic yard bucket; this works more satisfactorily in running sand, doing 200 feet to 400 feet a day. Where running sand or much water is encountered, the trench has to be timbered with sheet-piling. An illustration of this machine is given on plate 4. It lifts its own track ahead and has the great advantage that it can also be used for back-filling the trench when the pipe is laid.

Measurements are made of the discharge from the drains. During 1913 the "I" drains discharged as much as 7.7 cusecs at the height of the irrigating season and 5.5 cusecs in August and September, and the whole "I" system was not yet completed. The total maximum discharge of all the drains during the irrigating season is about 25 cusecs, and the average flow is not much less than 10 per cent. of the average flow sent down the main irrigating canal. It is interesting to note that the curve of total drain discharge during the irrigating season is roughly similar to that of the main canal discharge, the peaks of the former curve being only a few days behind those of the latter. The maximum drainage inflow per mile length of drain is 3.7 cusecs in the open drain A. Part of this seepage is due to excessive use by irrigation, but much of it is due to the fact that the Garland canal, for some distance below all the drops cuts through the top clay and runs in porous gravel, and also to the heading-up of the Frannie canal, which is of too big a capacity for the area at present irrigated.

The effect of the drains is noticeable very shortly after construction, and large areas have been reclaimed. On one section where the drain was constructed in October the water-level within 2000 feet on each side was lowered by from 2 feet to 5 feet by the end of the year. The average cost of completed tile drains has been about $1½ per foot run. Of this about 60 per cent. is for excavating trench and laying pipe, 20 per cent. is for back-filling the trench, and 20 per cent. for purchase of pipe. The estimated cost of future drainage is about $1.70 per foot run.

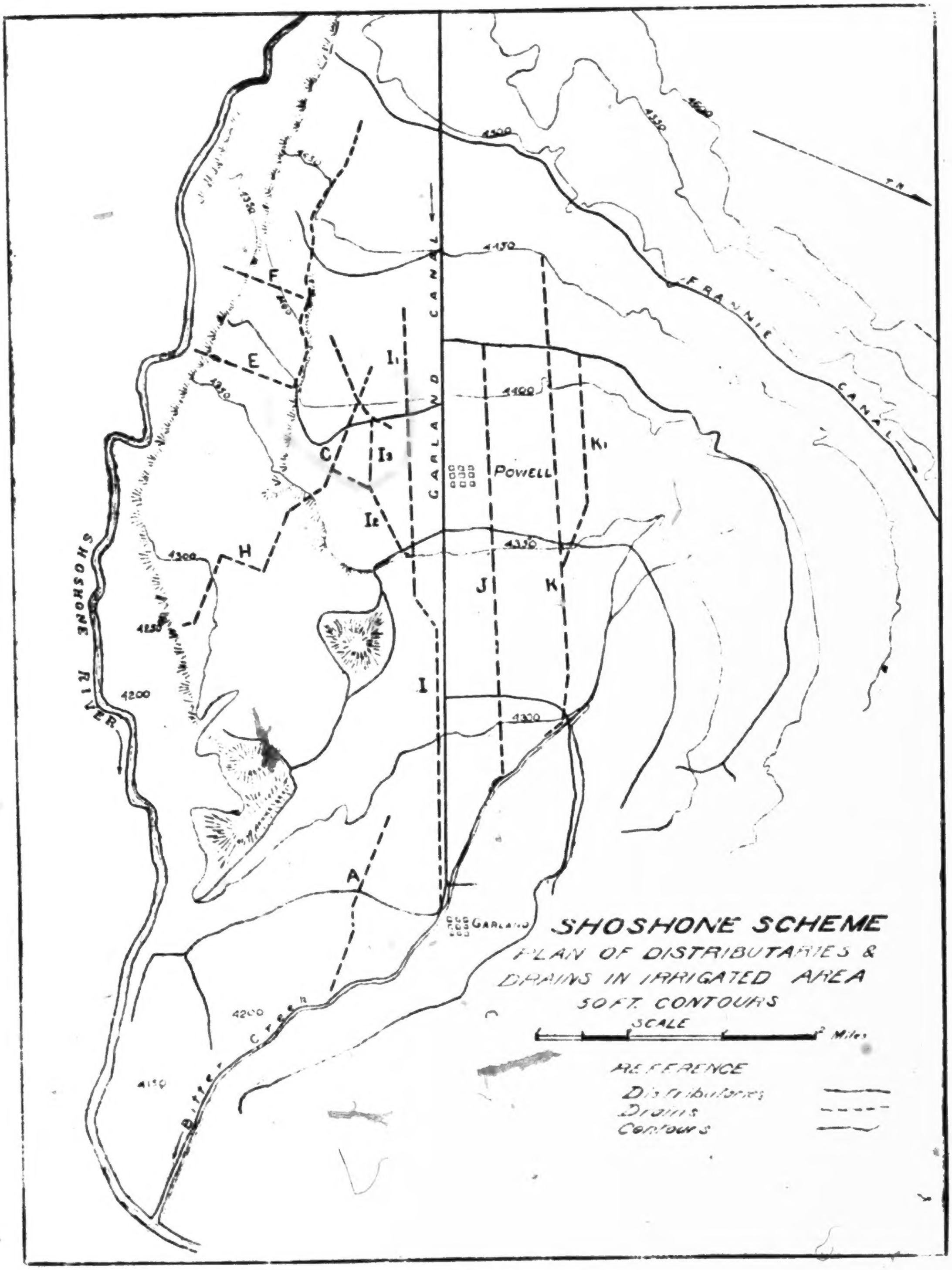

SHOSHONE SCHEME
PLAN OF DISTRIBUTARIES &
DRAINS IN IRRIGATED AREA
50 FT. CONTOURS
SCALE
2 Miles
REFERENCE
Distributaries
Drains
Contours
SHOSHONE RIVER
GARLAND CANAL
FRANNIE CANAL
POWELL
GARLAND
Bitter Creek
4500
4550
4600
4450
4400
4350
4300
4250
4200
4150
A
C
E
F
H
I
I1
I2
I3
J
K
K1

Fig. 13.

The surface of the irrigable ground is fairly even, and the slope is about 28 feet per mile, so that not much levelling is required and irrigation is easily carried out by simple surface flow with or without side borders. The irrigating stream is about 1 to 2½ cusecs.

Crops.

About 16,500 acres were irrigated in 1912. Of this about 50 per cent. was lucerne and 40 per cent. cereals. In 1912 the lucerne gave an average return of rather less than 2 tons per acre for three or fewer cuttings. Wheat gave a return of about 15 bushels per acre. The average price of lucerne was $6.50 per ton, and of wheat 60 cents per bushel. A mill has been erected in the centre of the lands for grinding up lucerne into a meal, which is sold in bags. It is capable of grinding 30 tons a day, and supplies a ready market for the lucerne, $6.50 being paid per ton delivered loose at the mill.

Settlement and Cost.

The whole area contemplated for the scheme, when completed, is about 164,000 acres, of which only about 1 per cent. was privately owned. The scheme is completed only so far as to be able to irrigate one-quarter of the above area, or 41,000 acres. The area signed up for water contracts is only 22,000 acres, although about 39,000 acres have been thrown open for entry in sections since 1908.

Of the 22,000 acres under water contract, only 16,500 acres were actually irrigated in 1912, or only about 10 per cent. of the contemplated scheme.

The cost of the construction to date has been $3,787,000, of which the storage dam cost about 1¼ million dollars and the Corbett weir and tunnel about the same. The chief works required to complete the scheme are the Frannie canal extension, the south bank canal, and the high-line canal, and these are estimated to cost $3,850,000, which will make the total cost $7,637,000 for an area of 164,000 acres, or $48 per acre.

The building charge to settlers has been raised successively from $45 to $46, and then to $48 per acre payable in ten equal annual instalments. As settlers found great difficulty in making payments for the first few years, in 1912 easier terms were made, the ten instalments being graded so as to be lighter in the first few years, the totals, however, being raised to fifty, fifty-one, and fifty-two dollars respectively.

It must be confessed that the above figures are a little disappointing, and the chief cause for disappointment is the slow rate of settlement. Of the 39,000 acres thrown open only 22,000 have been taken up, 17,000 acres still begging ownership. In 1912 about 4400 acres were taken up by new settlers, but 1600 acres were relinquished by old settlers and 700 acres were cancelled for non-payment.

The chief drawback to settlement is the appearance of alkali, which has frightened away home-seekers.

The scheme provides these two useful lessons to those promoting irrigation settlement schemes on a business basis:—First, seepage and alkali may appear where least expected, and due allowance must be made for such contingencies in estimates of cost. Second, settlement may proceed at a much slower rate than anticipated, and allowance must therefore be made for a fairly long initial period when expended capital is not being repaid. In this scheme, four years after 50 per cent. of the estimated expenditure had been incurred, including the storage dam which is to serve the whole scheme, only 13 per cent. of the estimated lands were under water-contract.

The annual charge to settlers for operation and maintenance has been $1 per acre irrigable, which therefore brings in at present only $22,000. The actual cost to Government is about six times as much, but 5-6ths of this is for betterment—mostly drainage. Cleaning of the larger distributaries gives very little trouble, most of the expense being in the smaller ditches which become overgrown with sweet-clover, foxtail, and swamp grass. Lucerne has been sown on some of the smaller ditches, as it is found to keep down other growths while giving little trouble itself.

The maximum size of farm allowed each settler is 80 acres, though original owners may retain up to 160 acres.

Distribution of Water and Duty.

Two superintendents and ten ditch-riders attend to the distribution of water, which is on demand by the settler as it is at Bellefourche and Huntley. A limit of 2 feet depth applied per season is in force, and any one using more than this has to pay 80 cents per acre-foot used. The average application at the fields in 1912 over the 16,500 acres irrigated was 1.66 foot, and about 1.11 foot was lost in the canals (apart from what was escaped to the river), so that the application measured at Corbett weir was 2.77 feet.

We have seen that 50 per cent. of the area is sown with lucerne, and therefore this crop is the dominating factor in water demand. It is interesting to note the effect of a single crop, such as lucerne, when occupying the largest area on one scheme. We get what might be called "lucerne peaks" in the supply curve, especially when rain falls in spring uniformly over the whole area and starts the first crop of all the lucerne simultaneously. It is the practice to irrigate shortly before cutting one crop for the sake of the next crop, so that the latter may come on while the hay is being made and carted from the last crop. Consequently there is an enormous demand for water just before the first cutting, and this wave of demand reappears more or less suddenly with subsequent cuttings and we get a series of "lucerne peaks" in the canal discharge just before each cutting. Sometimes two waterings per cutting are given in mid-summer. The following figures, taken from the 1912 and 1913 discharges of the main canal, will illustrate how these peaks occur:—

Started Irrigating.	1st Maximum.		Intervening Min. Cusecs.	2nd Maximum.		Intervening Min. Cusecs.	3rd Maximum.	
	Date.	Cusecs.		Date.	Cusecs.		Date.	Cusecs.
April 21, 1912...	June 4–6	345	120	July 13–14	320	100	Aug. 28	220
April 20, 1913...	June 8–10	350	50	July 19–21	405	110	Aug. 21	335

After the third maximum the discharge gradually falls off and it stops in October.

It is important, therefore, in a scheme having the greater area down to lucerne, to take notice of these peaks in designing the capacity of canals and in arranging any system of rotation. No rotation has yet been practised on this scheme, but it is proposed to adopt before long a five-day period rotation.

CHAPTER IV

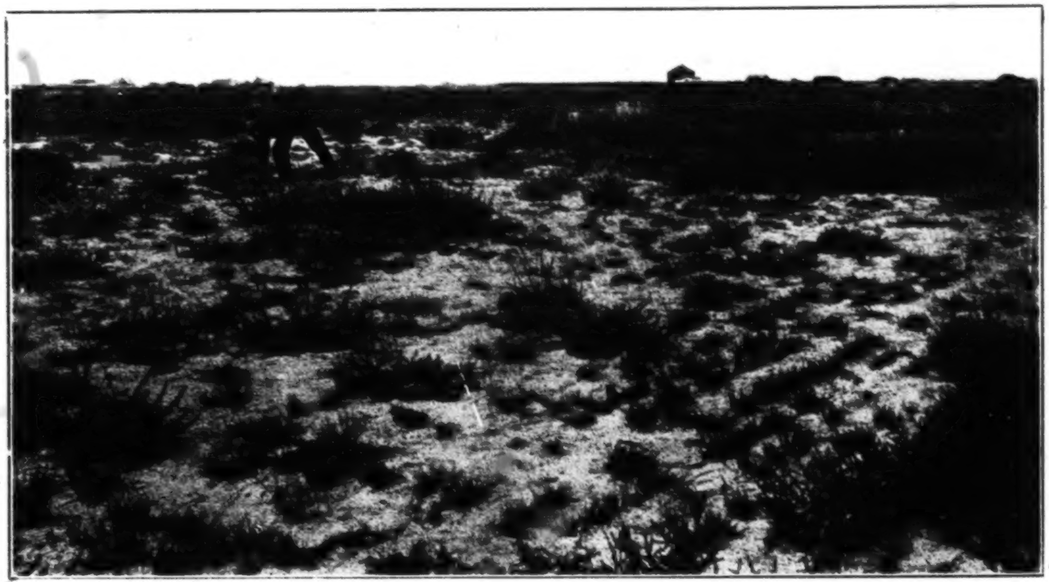
BOISE SCHEME

(*United States Reclamation Service, Idaho*)

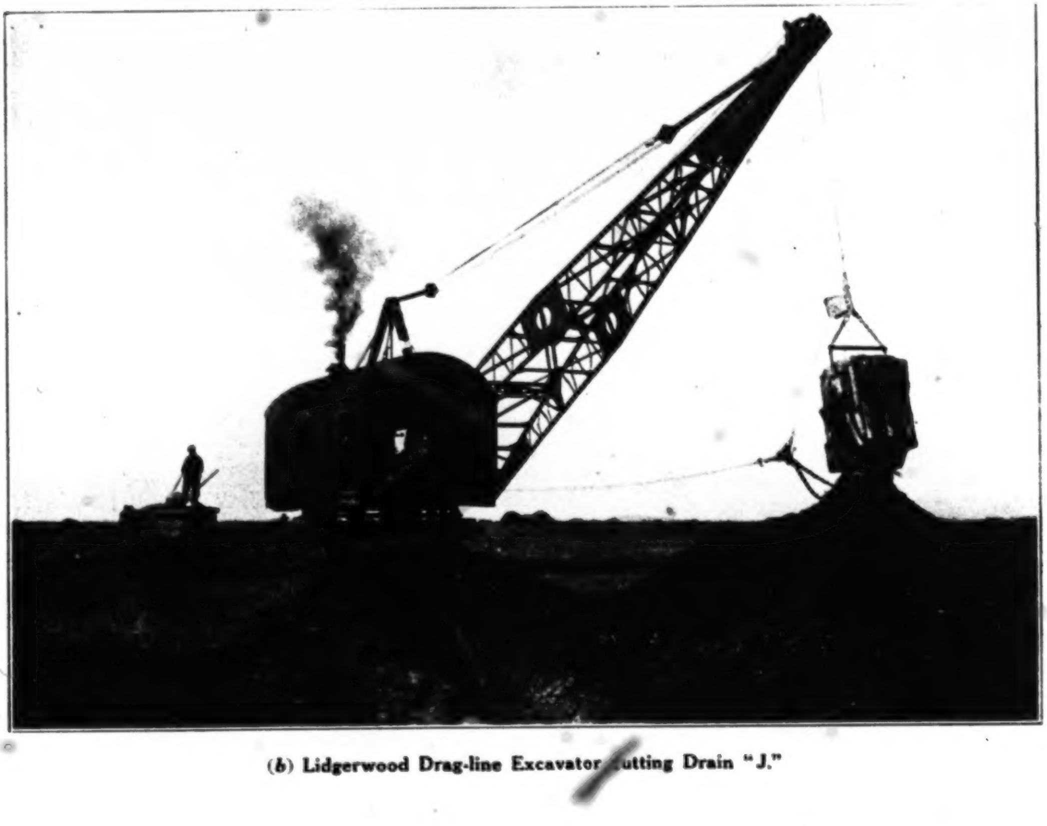
Locality.

This scheme is situated in the south-west corner of Idaho, on the Boise River, which flows westwards to join the Snake River on the borders of Oregon State. Idaho, like Montana, has its northern border on the boundary of Canada, and it is strange that, although so far north, these two States rank next to California and Colorado in the extent of irrigated land. In Idaho alone the acreage included in projects is nearly 4,000,000, for 70 per cent. of which works are already completed and nearly half actually irrigated. The greater

SHOSHONE SCHEME.



(*a*) Appearance of Alkali.



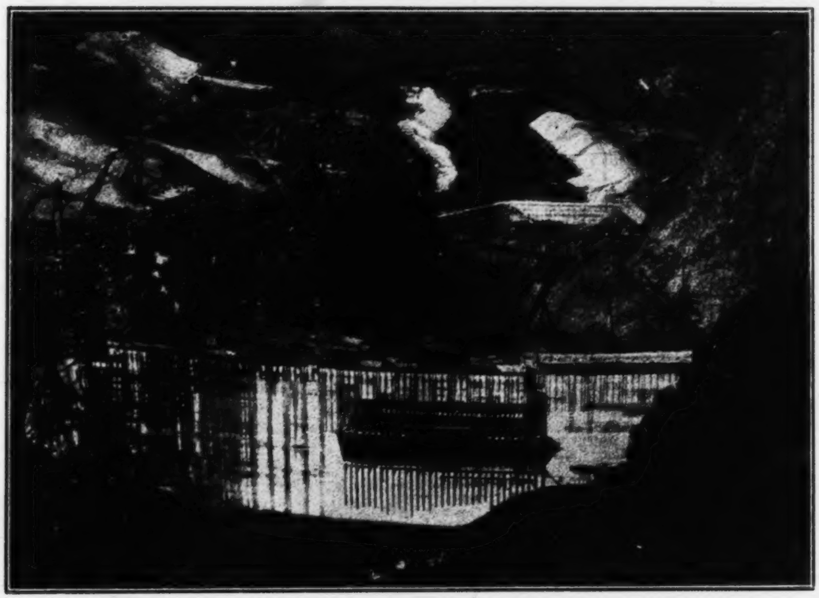
(*b*) Lidgerwood Drag-line Excavator Cutting Drain "J."

Plate 4.

SHOSHONE SCHEME.

(*c*) Drag-line Excavator. (Lidgerwood Manufacturing Co., Chicago.)

BOISE SCHEME—Arrowrock Dam.

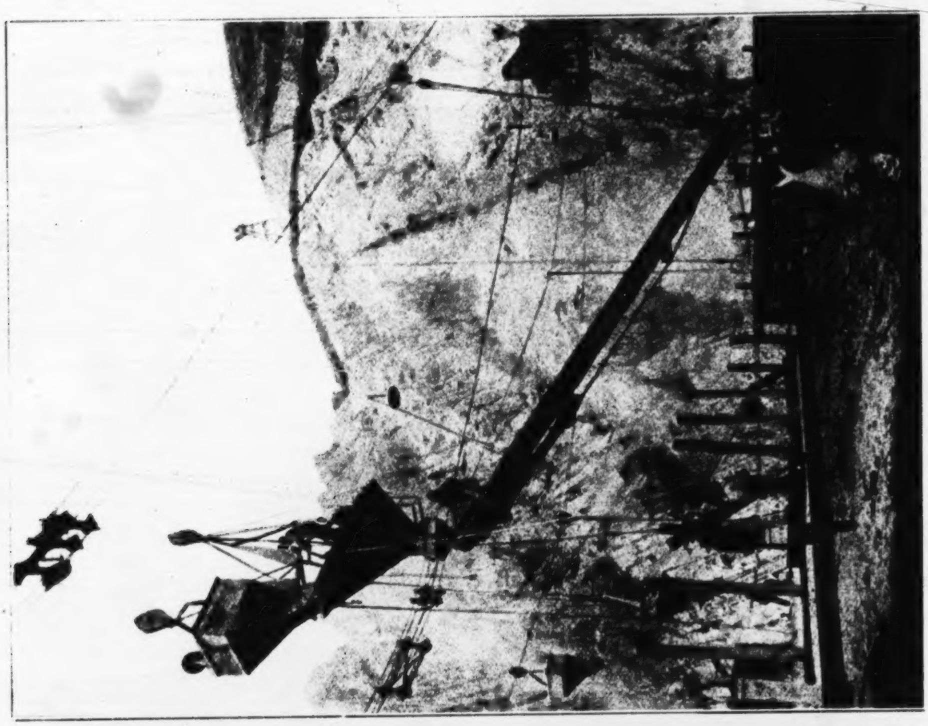


(*d*) Looking down-stream.

Plate 5.

BOISE SCHEME—Arrowrock Dam.

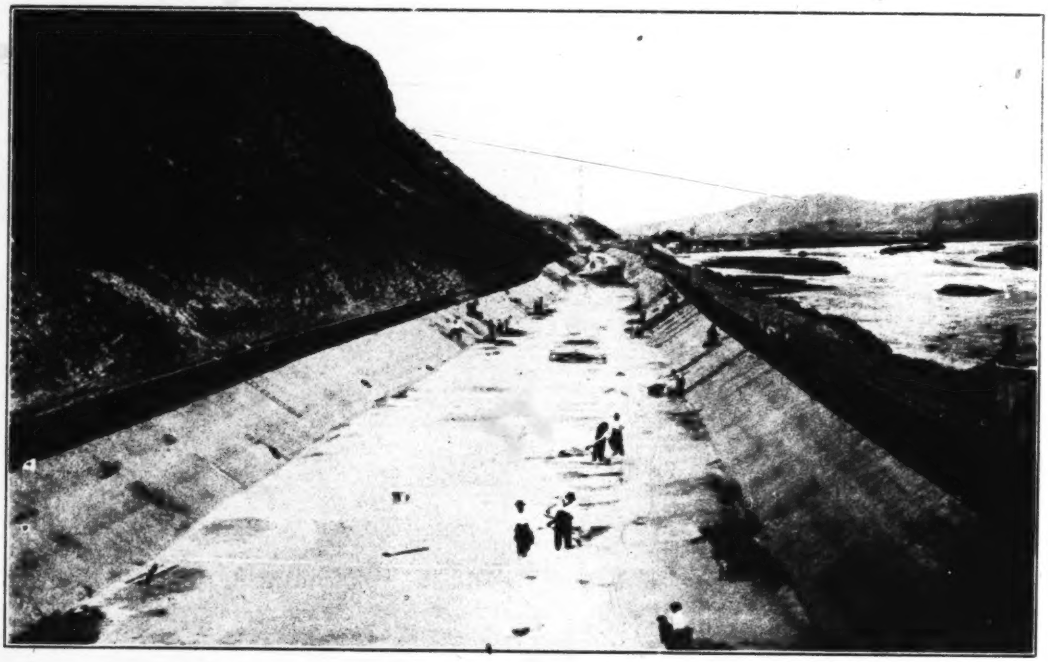
(*a*) Foundation-rock.



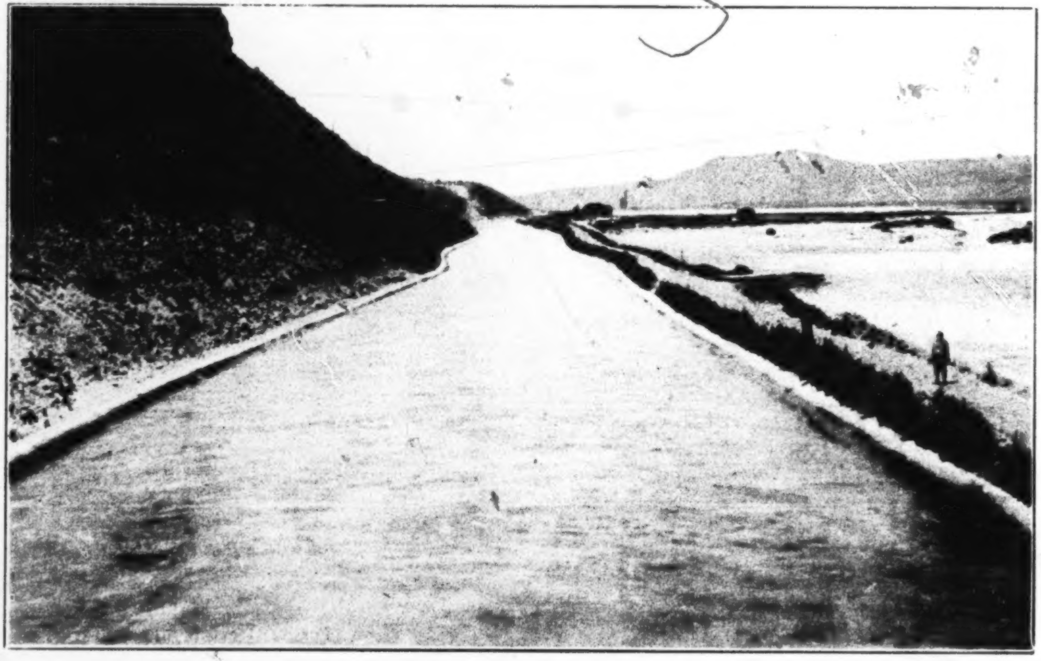
(*b*) Method of Concreting. Note cobbles and drain-pipes.

Plate 5.

BOISE SCHEME—Main Canal.



Concrete-lined, near Diversion Weir.
(c) Laying Concrete Lining—looking down-stream.



(d) Canal running full.

part of the irrigation is, however, in the south of the State, at about latitude 43 degrees north, which corresponds with the north of Spain or central Italy. The irrigated parts are mostly in the low Snake River valley, which runs from east to west through the State, protected on the north and east by the Rocky and other high mountain ranges, and on the south by ranges not quite so high. Moreover, as the State is on the western side of the great continental divide, the westerly winds which prevail, coming from the Pacific, have a great influence in moderating extremes of temperature.

The outstanding geological feature of the whole of the Snake and tributary valleys is the huge area covered by horizontally bedded lavas of Tertiary age, often interbedded with lake beds or river gravels. This is the source of most of the soils of the valley, which consist largely of a light loam, rich because of its volcanic origin, and often well drained by underlying gravel beds.

The oldest exposed formation is a granite, of which large areas appear north of the valley, and in the Boise Gorge, above the town of Boise, this is fortunately exposed beneath the lava bed and supplies an excellent foundation for the lower part of the Arrowrock dam.

The average altitude of the irrigable lands is about 2500 feet, and although in the higher northern parts of the State the mean temperature for six months of the year is below freezing point, yet at Boise—and generally in the lower valleys of the south—the climate is much milder and the summer quite warm. The temperature at Boise varies from −28° F. to as high as 107° F., and the irrigating season lasts from 1st April to 1st November.

Rainfall and Water Supply.

The average rainfall over the scheme is about 13 inches, and this falls mostly in winter and in early summer. The driest months are July and August, when water is urgently needed for irrigation, and, on rivers like the Boise, which derive most of their flow from melting snows on comparatively low ranges, these two are the months when the flow is rapidly diminishing, so that storage is being found necessary where irrigation has developed rapidly.

The drainage area above irrigation on the Boise River is 2610 square miles, fairly steep and well-wooded. The mean annual run-off is 2,200,000 acre-feet, and the maximum and minimum observed are 3,100,000 and 1,200,000 acre-feet. The curve in fig. 14 shows the mean discharge for a period of eleven years. A single yearly discharge curve naturally shows more peaks, and discharges of over 20,000 cusecs have been recorded for short periods, 28,000 being the maximum.

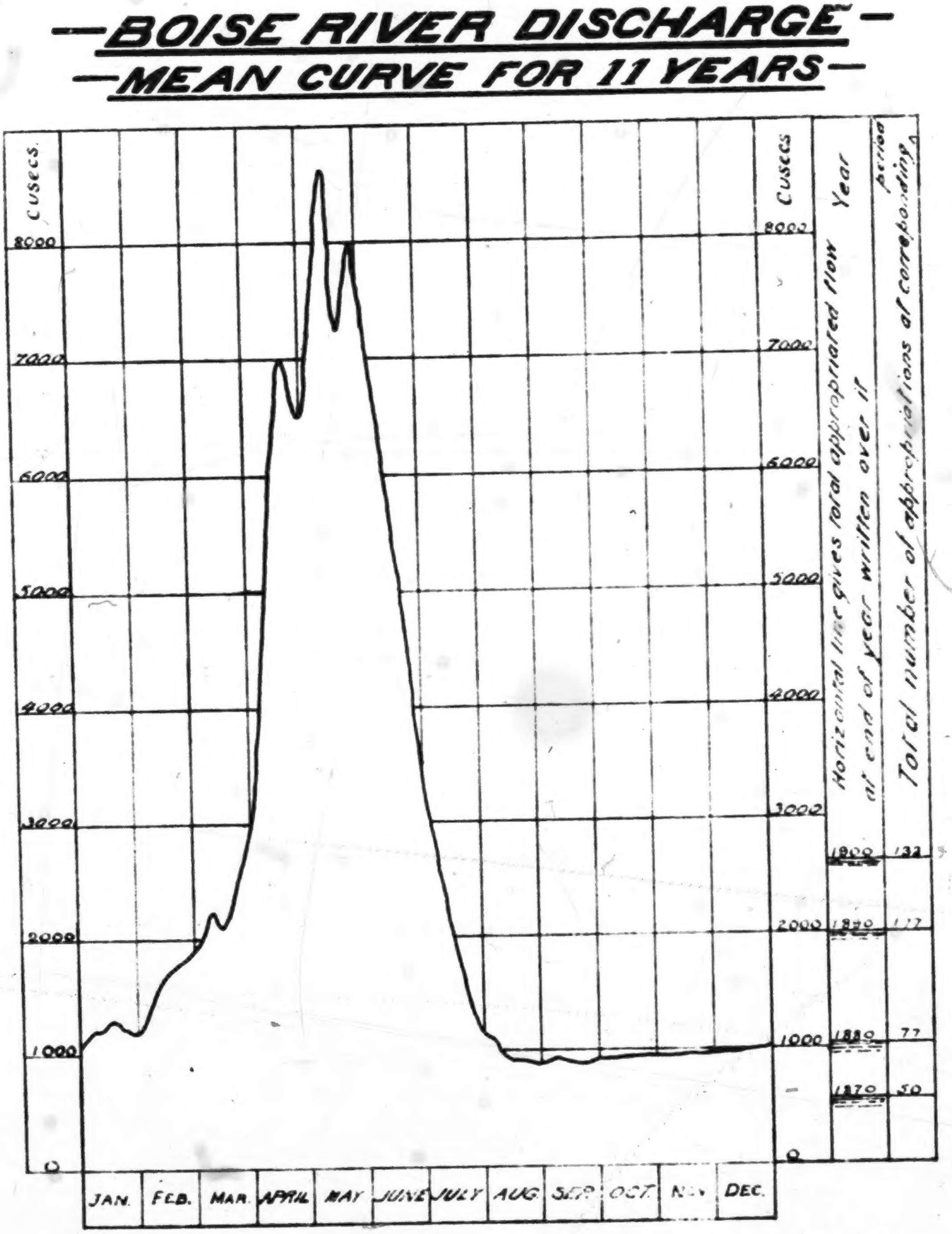
It will be observed from the mean curve that the discharge falls off rapidly during July and runs more or less uniformly between 800 and 1000 cusecs for the remaining months of the year. Now, Government began construction only in 1905, and, before that, development had been going on steadily by private enterprise for half a century. As each scheme developed it acquired rights by appropriation, and (by 1904) 135 rights had been established to a total flow of 2755 cusecs. This means that any development after 1904 could take water only at such times as the flow exceeded 2755 cusecs, which, in a mean year, would be from 1st April to the end of the first week in July. Storage was therefore essential, and this is supplied by the Deerflat reservoir, commanding the lower lands (completed in 1912) and the Arrowrock dam (now in course of construction) commanding all the lands. The aim of the scheme is not only to provide irrigation for about 67,000 acres of new Federal lands, but also to provide better irrigation for about 153,000 acres of land privately owned and not developed, or included in an irrigation district which has an insufficient water supply, or too late an appropriation without storage. The function of the Federal Government is therefore quite different in this case from that which we have noted in the three previous schemes, where older private works do not cover the same area.

The Federal Government is enabled to provide better irrigation for older and highly developed areas by virtue of the Warren Act of 1911, and this work is almost as important as the development of entirely new areas.

It will be seen from the table of appropriation (on the right of the mean discharge of fig. 14) that as early as 1878 the total appropriation exceeded the mean low-water flow for August and later months, so that storage is really required for all the appropriations after 1878. The two most important irrigation districts which have late water-rights and require additional water are the Nampa-Meridian and the Pioneer irrigation districts (shown on plan, fig. 15). Government has made contracts for supply with both of these.

Outline of Scheme.

The Arrowrock storage dam is being constructed across the Boise River in the canyon, about 23 miles above Boise city. Fifteen miles below the dam a high diversion weir is built across the river, and the main canal starts from it on the south side. It keeps close to the river for two miles and then gradually gets away, and, opposite Boise town, turns off sharply and runs at the foot of the high land bordering the irrigable area. At about its twenty-sixth mile, Indian Creek is



Total appropriations in 10 year periods on right of Diagram

Fig. 14.

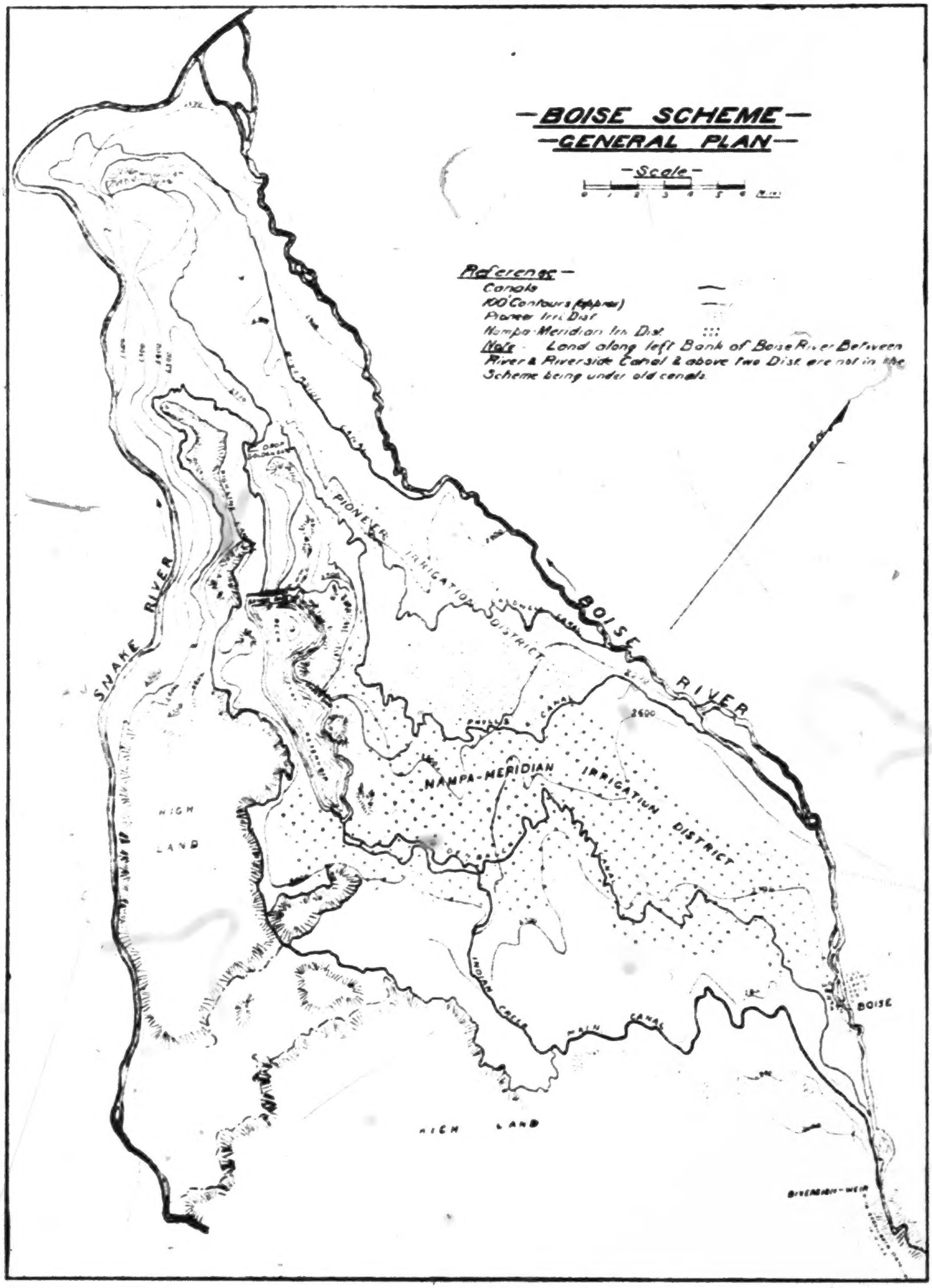

-BOISE SCHEME-
-GENERAL PLAN-
-Scale-
0 1 2 3 4 5 6 Miles
Reference -
Canals
100' Contours (approx)
Pioneer Irr. Dist
Nampa-Meridian Irr. Dist.
Note - Land along left Bank of Boise River Between River & Riverside Canal & above two Dist are not in the Scheme being under old canals.
SNAKE RIVER
BOISE RIVER
PIONEER IRRIGATION DISTRICT
NAMPA-MERIDIAN IRRIGATION DISTRICT
HIGH LAND
HIGH LAND
INDIAN CREEK MAIN CANAL
2600
BOISE
DIVERSION WEIR

Fig. 15.

crossed, and this creek is used for 9 miles to take the supply down the steep slope to the Deerflat reservoir, the remainder continuing in a canal at the foot of the hills to irrigate the high lands along the ridge bordering the Snake River. The Deerflat reservoir, situated about the middle of the irrigable lands, stores surplus water and supplies stored water to the lands lying below it.

The Ridenbauch canal, which takes out of the river below the diversion weir, supplies the Nampa-Meridian irrigation district, and the Phyllis and Caldwell canals—still lower down the river—supply the Pioneer district, and all these three older canals now derive additional water from the new Government scheme.

Detail Works.

THE ARROWROCK DAM.

Site.

Above the diversion weir the valley of the Boise River contracts into a narrow canyon with high rocky banks rising from near the water's edge. About 15 miles above the weir is the site of the great Arrowrock dam. This is now in course of construction, and will be the highest dam in the world. The site is just below a sharp bend in the river. The old granite formation is here exposed and provides an excellent foundation for the greater part of the dam. On the right bank the granite rises steeply from the river bed and is clearly exposed.

The river bed consisted of sand, gravel, and boulders to an average depth of 70 feet, but as deep as 90 feet in one place, and very good granite has been found below it.

On the left bank granite is found up to a little above the river bed, and then a cap of lava about 50 feet thick overlies the granite, rising almost sheer on the river side and running nearly horizontally away from the river for about 60 yards. The junction of the lava and granite (clearly shown on the left of photo D, plate 4) appears to be remarkably close and free from any sort of loose material, and the lava itself is hard and freer from long continuous cracks than we might expect in such a formation. The lava bed thins out further from the river, the underlying granite rising again, and both are covered thinly with soil which continues over the rock at a gentle rise to crest-level on the left bank. At the maximum section the height of crest above foundation is to be 344½ feet and the parapet 4 feet higher. Of the above height, 90 feet are below the natural loose bed of the river. In respect of the foundations the site is

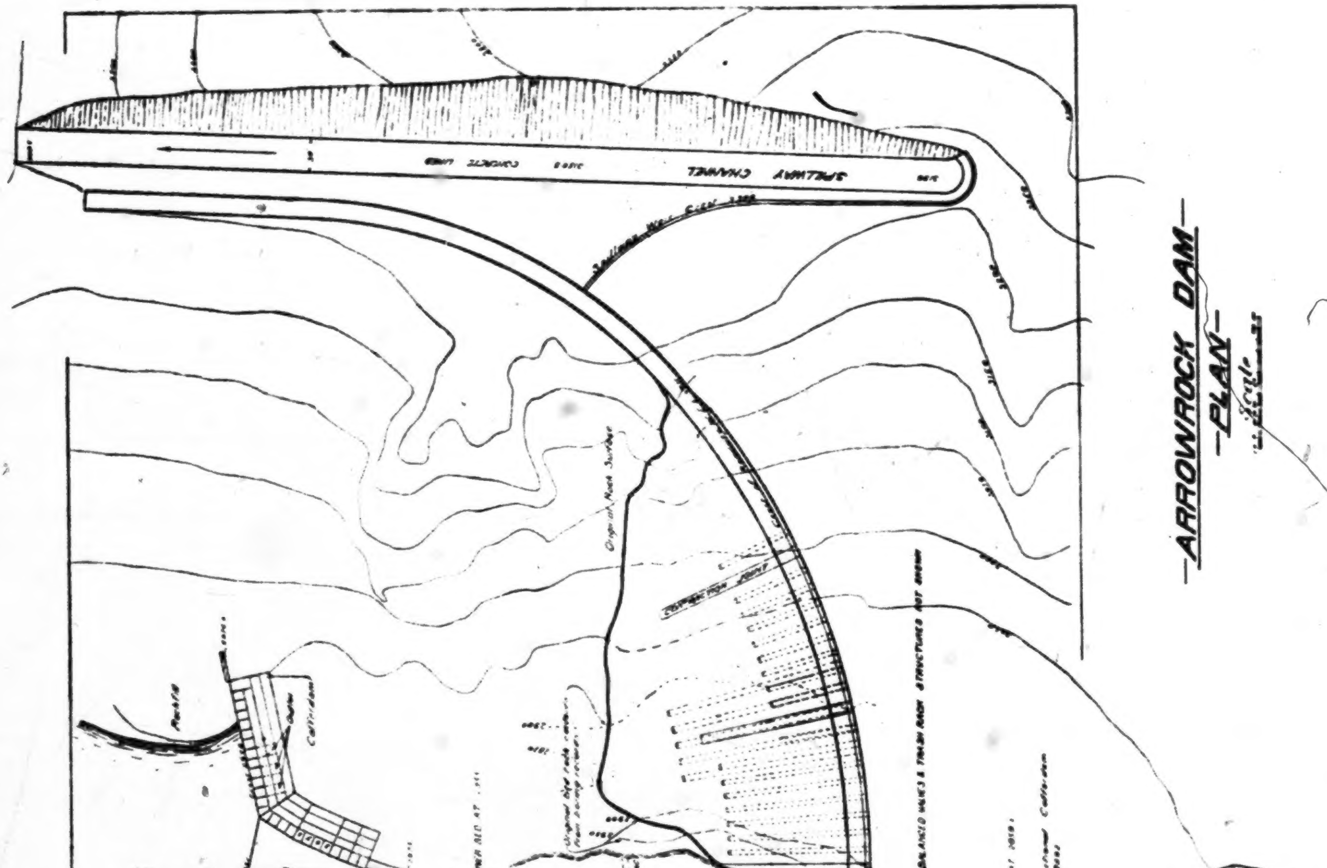
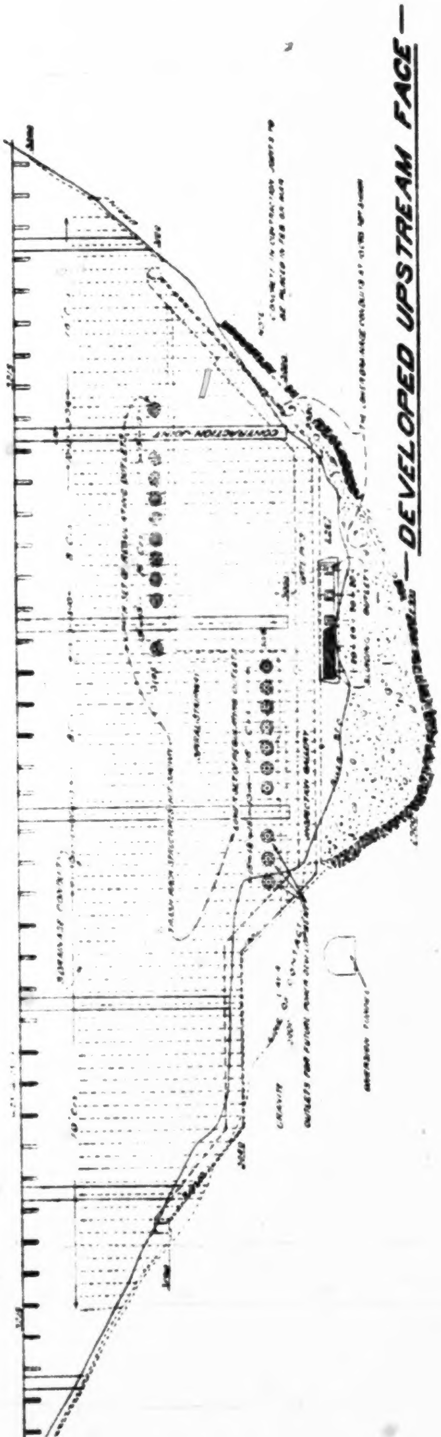

-ARROWROCK DAM-
-PLAN-
Scale
SPILLWAY CHANNEL
DIVERSION TUNNEL
BOISE RIVER
BALANCED VALVES & TRASH RACK STRUCTURES NOT SHOWN
Construction Cofferdam
Original Rock Surface
Original Earth Surface
Cofferdam

Fig. 16.


CONTRACTION JOINT

—DEVELOPED UPSTREAM FACE—

Fig. 17.

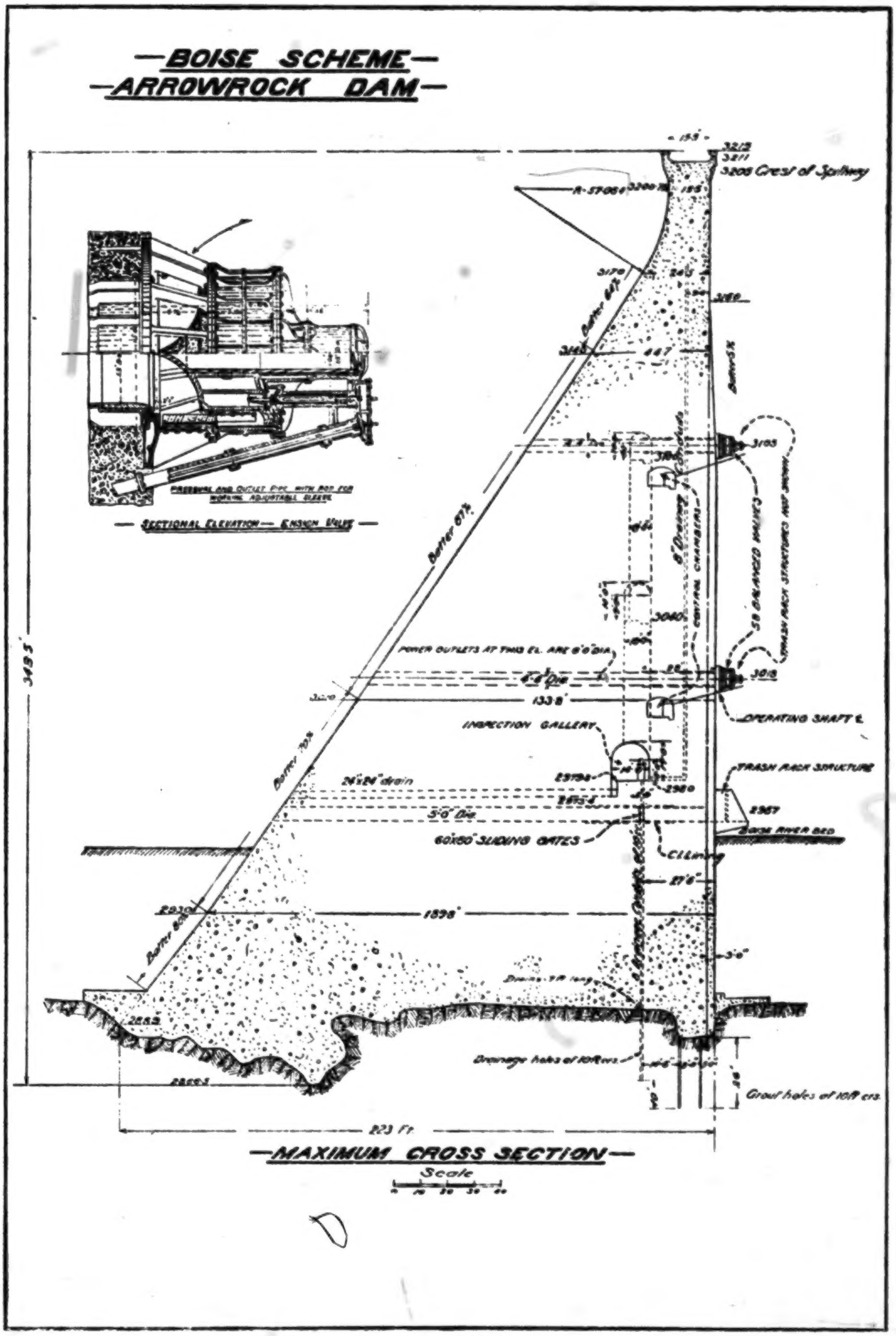
excellent, and the width of the canyon is not excessive: but the storage basin is not as good as it might be and does not give the storage we might expect from such a high dam. The valley is steep and narrow. Two branches of the river join about 4 miles above the site, and the water will stand back in both for about 18 miles from the dam, and the capacity will be about 230,000 acre-feet.

Design. The width of the canyon at crest-level is about 985 feet. With so great a width it is impossible to rely on arch action in a curved dam as was done at Shoshone. Treated as an arch or segment of a cylinder, an impossible width would be required in the upper parts. The design adopted is therefore a gravity section, but, in addition, the dam has been curved in plan to a radius of 662 feet. This gives a length (on the centre line of the crest) of 1050 feet, which subtends an angle of 95 degrees at the centre, or slightly wider than the 90 degrees angle adopted for the dam at Roosevelt, where, however, the crest-length is considerably less. It is evident that the designers consider the arch form of some assistance, even with a crest-length of over 1000 feet.

The maximum cross-section is shown on fig. 18. It will at once be noticed what a simple and light section it is. A very high compressive strength has, therefore, been allowed in the concrete. With the exception of a slight widening of 3 feet in the upper portion and a very small footing projection, the up-stream face is vertical.

There is not even a curve at the toe, and the absence of batter, especially in the lower part of this face—such as we have been accustomed to see in other high dams—is worthy of note. The down-stream face to a depth of 201 feet below the crest has a slope of 1.5 on 1 for the greater distance, and is steeper in the top part. In this 201 feet the usual condition of keeping the resultant just within the middle third has been closely observed. This gives a maximum pressure on horizontal planes of about 13 tons per square foot at this depth. From this point the slope is slightly flattened to 1.43 for the next 80 feet, beyond which point a further flattened slope of 1.25 carries the face to the bottom, meeting the foundation at a depth of 322 feet, where, neglecting a small footing, the width to the plane of the up-stream face is only 223 feet—a remarkably small width for such a high dam.

The maximum compressive stress in the concrete will be about 23 tons per square foot on horizontal planes, and higher on sloping planes. This is probably a greater compressive limit than has ever



—BOISE SCHEME—
—ARROWROCK DAM—

—SECTIONAL ELEVATION— ENSIGN VALVE—

—MAXIMUM CROSS SECTION—

PRESSURE AND OUTLET PIPE WITH BOX FOR WORKING ADJUSTABLE SLEEVE
15.5'
3213
3211
3205 Crest of Spillway
R-57.08'
3200.78
15.5
3170
24.5
3160
Batter 6.1/2
3145
44.7
Batter 5%
3105
33 1/2 Dia
3100
8" Drainage Conduits
CENTRAL CHAMBERS
58 BALANCED VALVES
TRASH RACK STRUCTURE NOT SHOWN
3040
POWER OUTLETS AT THIS EL. ARE 6'0" DIA.
4-4 1/2 Dia
3018
Batter 67%
Batter 70%
3010
133.8'
OPERATING SHAFT ℄
INSPECTION GALLERY
2979.4
2980
24"x24" drain
2975.4
TRASH RACK STRUCTURE
2967
5'0" Dia
BOISE RIVER BED
60x60" SLIDING GATES
C.I. Lining
27'6"
349.5'
2930
189.8'
Batter 80%
3'0"
Drains 7 ft long
2882
2829.5
Drainage holes at 10 ft ctrs.
Grout holes at 10 ft ctrs.
223 Ft.
Scale
0 10 20 30 40

Fig. 18.

been allowed in a gravity-section dam. In the Australian arched dams of no great height a pressure of 20 tons per square foot was safely allowed, and in the famous Bear Valley arched dam the stress is said to reach 40 tons, but in purely gravity-section types the highest vertical stress previously allowed was 16-17 tons per square foot in the New Croton and Roosevelt dams, and this was at the time a great increase in the value previously considered safe.

As the foundations are excellent and the concrete is being laid with the greatest care, there seems to be no reason why such a pressure should not safely be allowed, especially when we consider that, by the time the lowest layer has to bear this load, it should have a compressive strength of at least 150 tons per square foot.

Contraction Joints.

Another feature in the design is the provision of radial contraction joints in the upper part of the dam. Good concrete will contract 1-200,000th of its length for one degree fall in temperature, and if the modulus of elasticity is about 200,000 tons per square foot and the ends are fixed we shall get a tension of about 1 ton per square foot for every degree fall of temperature below that at which the concrete was placed. Great changes of temperature cannot be expected in the lower massive parts of the dam, usually covered with water, but in the upper portion, which is more exposed and thinner, considerable changes of temperature are likely to occur. This clearly indicates the necessity of building the dam, especially the upper part, at the lowest prevailing temperature to prevent cracking due to tension at the coldest times. It is obviously impossible to build the whole structure in mid-winter, and consequently the plan is adopted of building the dam in sections throughout the year, leaving a number of radial gaps between each to be filled up in mid-winter. In this dam the radial gaps are 10 feet wide and 150 feet apart. This arrangement gives three contraction joints in the deepest part of the dam; these are begun a short distance above low-water level and carried up vertically 211 feet to the crest.

Drainage of Dam.

Another important feature is the provision for means of detecting and remedying any upward pressure near the up-stream face, due to cracks either undetected in the foundation or developed in the masonry above.

The first consideration is to make the foundation along the up-stream edge as impervious to water as possible. To this end a keyway 14 feet wide is excavated until the soundest possible rock is met. From the bottom of this two lines of grout holes are drilled at 10 feet intervals throughout the whole length of the dam. The front line is 5 feet behind the up-stream face and the second line 8 feet further back. These holes are drilled to a depth of 26 feet below the key-bed, and into them grout is forced under pressure, so that any possible cracks in the foundation reached by them will be grouted up.

In case, however, this fails to shut off completely any percolation from the up-stream side, another line of open drainage holes has been drilled 14 feet 6 inches behind the last grouted line, or 27 feet 6 inches from the face of the dam. These are drilled 26 feet into the foundation rock, and will of course be left open so long as no great flow develops in them. Over these vertical drains, and along the junction of the concrete with the foundation rock, small drains are left, extending horizontally 3 feet 6 inches each side of the vertical drain along the length of the dam. These, therefore, will form a broken line of horizontal drains along the junction of the concrete with the foundation in 7-foot lengths with 3-foot breaks between each. From each of these drains a vertical drain of 8-inch diameter staggered pipe is then constructed through the concrete up to the floor of the inspection gallery, which is always above the low-water level below the dam, and can therefore be drained to the river. We thus have, in addition to the grouted front row of holes, a series of open vertical drains, each extending 26 feet into the foundations and tapping a length of 7 feet horizontally along the contact. They are 10 feet apart and each is separate from the other, so that the appearance of any flow in one or more of these pipes will indicate some seepage past the upper face and enable one to locate it and to remedy it, for the inspection gallery is of such a size (14 feet × 14 feet) that a grouting machine may be set up and operated in it so as to grout up any holes that indicate cracks below.

These vertical pipes can be seen in photos D, plate 4, and B, plate 5, the work not having reached the height of the inspection gallery when these photos were taken. A further series of vertical drains is to be built in the part of the structure above the inspection gallery and extending to within 40 feet of the crest-level. These will also drain into the lower inspection gallery. They are 8-inch pipes, spaced 8 feet apart in the central part of the dam and 10 feet apart in the side portion, and all in a vertical plane 12 feet from the up-stream face. The total length of open 8-inch drains in the dam will be about 3¼ miles. This shows what great importance the designers attach to means of detecting any tendency to crack in horizontal planes near the up-stream face in the dam itself or in the foundations, even when the foundation rock is as good as it is here. Probably the closest observation of these drains will be made while the dam is first being filled. If any crack should then develop, the flow in the pipes through that neighbourhood will quickly indicate the fact, and by opening the sluice gates and lowering the water-level the upward pressure may be prevented from rising to such a value as might cause a breach and the defect be remedied before filling the dam again. As these drains are all in one plane in the upper part of the dam, and take up about 8 per cent. of the area, it is obvious that special care should be taken in placing the concrete that this plane does not become a plane of weakness.

Outlets. Outlets are provided at three levels. The lowest, in the middle, at just above the original bed-level, with centre line at 2967 feet, i.e. 244 feet below the crest, consist of five sliding gates, each 5 feet × 5 feet. These are for sluicing. The next outlets are ten 58-inch "Ensign" needle-valves with centre lines at 3018 feet, or 193 feet below the crest. These are all on the left side of the dam, and the three nearest the bank are for power purposes. The last and highest set consists also of ten 58-inch "Ensign" valves with centre lines at 3105 feet, or 106 feet below the crest. These latter are all in the right side of the dam.

The most remarkable feature about the outlets is that each is provided with a separate conduit through the dam, running horizontally and radially, the lowest or sluicing conduits being spaced 20 feet between centres, and almost all the others 16 feet, except near contraction joints. The conduits for the 58-inch valves are each of 52 inches diameter, and for the sluicing valves of 5 feet diameter. We thus have twenty-five separate circular conduits, none less than 52 inches in diameter, passing right through the concrete of the dam.

This is a great departure from the usual custom of making a large tunnel through the side of the foundation rock and using it as a common conduit for several valves. The chief reason for the new plan is that it has been found that in high dams, if several valves discharge into a common conduit, there results an enormous surging and throbbing which is liable to set up very dangerous vibrations. This is avoided by giving each valve opening a straight run into its own separate conduit, and to do this through the rock for twenty-five valves would be impossible on account of the expense and the shattering of the rock by blasting. The result is that, except for the 3 power conduits, all outlets will discharge straight down the river without any rock to break the force. One wonders what will happen to the gravel and boulders in the channel below. Probably a pool will form and act as a water-cushion. It will certainly be a fine sight to see the upper outlets discharging under a head of 95 feet and falling 145 feet to the river bed below. At a head of less than 30 feet the discharging water from the upper outlets would probably strike the down-stream face of the dam first, though the lower outlets would probably then be used.

Ensign Valves.

The fact that the "Ensign" valves are adopted shows that they have proved satisfactory where previously used, as at Bellefourche and the Roosevelt dam. The inspection gallery, running right through the dam a short distance behind the valves, allows the controlling taps to be placed nearer to the valves, and for this reason an additional control has been devised for some of the valves (see fig. 18). The end of the pipe to the valve is provided with an adjustable length, the opening of which is closed by a plug fixed to the back of the piston. By setting the adjustable length the extent of valve-opening can be more easily regulated. The piston, in opening after high pressure is removed, automatically comes to rest when the plug reaches the escape pipe, and thus prevents the escape of water from the cylinder. The rods for regulating the position of the sliding length of pipe pass through the fixed pipe from the operating chambers in the inspection gallery.

Spillway.

The spillway is on the right bank, and its crest is only 5 feet below the crest of the dam and 9 feet below the parapet level. A side valley comes in a short distance below, and by spilling into it the surplus water is carried clear of the dam. A spillway 400 feet long was required. There is no natural neck, and, as the sideslopes are very steep, to lessen excavation the spillway is built roughly square to the dam, in a curve extending up-stream along the face of the cliff. A bench is excavated and the spillway weir, 10 feet high, is built on this. Behind the weir a steep channel is excavated parallel to the river. This channel is roughly 800 feet long, 30 feet wide on bottom, with side slopes $\frac{1}{2}$ to 1 and longitudinal fall of 40 feet in the first 350 feet with curved profile, and thereafter level. It will be lined with concrete. The excavation for the spillway will be 350,000 cubic yards through granite. Most of this will be ground up for the sand required for sand-cement and concrete in the dam.

Materials of Construction.

The two most remarkable points about the materials are the use of a cement mixture instead of plain cement, and the use of cobblestones, passed through the mixers, instead of plums.

Sand-Cement.

Sand and cement are mixed in equal volumes and ground together in a mill to a very fine state, and it is found that the resulting mixture is just as strong and suitable as the original plain cement. It is obvious therefore that if the cost of grinding one barrel of the mixture is less than the cost of half a barrel of the cement delivered at the site, a considerable saving in cost will result. The cement as delivered is of such a fineness that 80 per cent. of it will pass through a 200-mesh sieve. This compares favourably with some of the best English cements. The cement and sand are ground together to a finer state, so that 90 per cent. of the result will pass through the same sieve. The sand is provided by crushing up granite excavated from the spillway and screening it through a 20-mesh sieve, which gives a fine enough sand to grind with the cement. A very large number of tests have been made on briquettes according to the American standard method, not of neat cement, but of a mortar mixed with standard testing sand in the proportion of 1 to 3 by weight.

The following average results were obtained after testing for a year:—

	Tensile Strength: lb. per sq. inch.				
	After 7 days.	After 28 days.	After 3 months.	After 6 months.	After 1 year.
Sand-cement mixture (ground half and half) ...	330	419	460	452	410
Portland cement	343	428	461	467	408
	Crushing Strength on 2-in. cubes: lb. per sq. inch.				
Sand-cement mixture (ground half and half) ...	1471	1763	2729	3121	3712
Portland cement	1077	1969	3720	3744	—

If, instead of 50 per cent. of sand, 40 per cent. or 30 per cent. is used, greater strength is obtained, but of course with less saving in cost. If 60 per cent. is used lower results are obtained, and with 70 per cent. sand the results are much lower.

The above comparison shows that the blend used produces just as good results as the unblended cement. Moreover, it acquires its maximum tensile strength more gradually and the subsequent falling off is less. It is not certain why the mixture gives such good results compared with unmixed cement. One theory is that it is simply the finer grinding that makes the cement more powerful; but tests have been made by comparing the finer-ground cement alone with the cement as delivered, and they have not yet conclusively proved this theory. It is certain, however, that very badly ground cements are improved by regrinding to a greater state of fineness. The other theory is a chemical one, and asserts that certain constituents of the sand, in a fine state, especially the colloidal or soluble silica, have a chemical action with the portland cement which increases its strength. Pure quartz sand, ground to a greater fineness than described above, contains very little soluble silica, and if the latter theory is correct would make a poor mixture, while igneous rock and sandstone have been found to give good results.

Cement delivered at Arrowrock (from Utah) costs a little over $2 per barrel (380 lb.). The cost of grinding a barrel of sand-cement, including sand-crushing, power, depreciation on plant, etc., is about 50 cents, so that a saving of about 50 cents is made on every barrel of sand-cement used, and about 500,000 barrels will be required for the whole work. The cost of the plant, complete with buildings and power, was $46,000.

The proportions of the concrete are 1 of blended cement to 2½ of sand and 5½ or 6 of gravel.

Cobble-stones in Mixers.

The interesting point is, however, that three volumes of cobble-stones (2½ inches to 6 inches) are added to the above and passed through the mixers at the same time, so that the proportion of blended cement to other materials is 1 to 11, and the proportion of portland cement is, therefore, only 1 to 22. This method had previously been adopted on the Keokuk dam and the New York Harbour Works, and has been proved to be satisfactory. It is obviously very much cheaper than setting plums in the placed concrete, a process which often led to very little saving in cost on account of the expense of handling. The absence of derricks on the dam is remarkable.

Methods of Construction and Plant.

The power for driving most of the plant is electricity, and is derived from the generating station at the diversion weir, 15 miles below the dam. Here there is an available head of about 30 feet. Three twin Francis turbines, each of 860 h.p., are erected. The axis is vertical and directly connected with the alternating current dynamos (Allis & Chalmers), which generate 3-phase 60-cycle current at 2200 volts. This is stepped up to 23,000 volts and sent to the work in two 3-wire conductors.

Sand-Cement Plant.

The granite from the spillway excavation is being used for the sand. The rock is blasted by firing first dynamite to spring the holes and then black powder to break up. A 70-ton "Atlantic" steam shovel (Bucyrus), with 2½ cubic yard dipper, loads the loose material into flat skips (with 3-chain suspension) lying flat on the trucks of a small railway working in the spillway. A 10-ton "American Hoist and Derrick Co.'s" stiff-leg derrick lifts these skips and drops the rock into a crusher (Austin No. 5 and Gates' rotary crushers are used).

After passing a rotary screen the material is run down an open wooden shoot to the lower level near the sand-cement plant. It is then passed through a ball-mill, which further reduces the size, and then through a dryer, and, after passing a 20-mesh sieve, is ready for the sand-cement mill. A mixing machine adds the proportion of cement, and the grinding is done in three tube-mills, 5 feet in diameter and 22 feet long, with very hard stones inside. This plant is capable of turning out 1000 barrels in twenty-four hours and requires about 400 h.p. to operate it.

The sand-cement is conveyed to the concrete mixers, high on the other side of the river, by blowing it through pipes. The wear at bends in these pipes is considerable.

Cableways. For the conveyance of all materials over the line of the dam, four cableways are erected. Two of these are fixed at such a high level as to do all the work right up to crest level. They are Lidgerwood patent locked-steel cables with patent fall-rope carriers.

The span is 1500 feet, and the height of head-towers is 60 feet, and of tail-towers 100 feet. Although only two cables are provided, three sets of towers are erected, so that any cable can be shifted up or down stream. The three tail-towers are close together, over the motor-house, and the three head-towers are far apart. The cables are designed for a 15-ton load, and actually handled this load when the 70-ton steam shovel was lifted from the river bed to the spillway in parts, some of which weighed as much as 15 tons. Each cableway is operated by a 300-h.p. motor at 2200 volts. The hoisting speed is 300 feet per minute, and the travelling speed is 1200 feet per minute. These cableways were used for conveying the excavated material in 4 cubic yard skips from the river bed to the screening and crushing plant, and also operated "orange-peel" and "clam-shell" buckets.

Concrete Conveyors. Operating at a much lower level are two "Crowe" concrete-placing cableways and equipment, and most of the concrete which cannot be directly fed through shoots from the mixers is placed by means of them. The way in which they work is clearly shown in photo B, plate 5. The travelling hopper, of 2 cubic yard capacity, automatically discharges through a radial gate into a stationary hopper which is suspended from the same cable and can be fixed at any height

Plate 6.

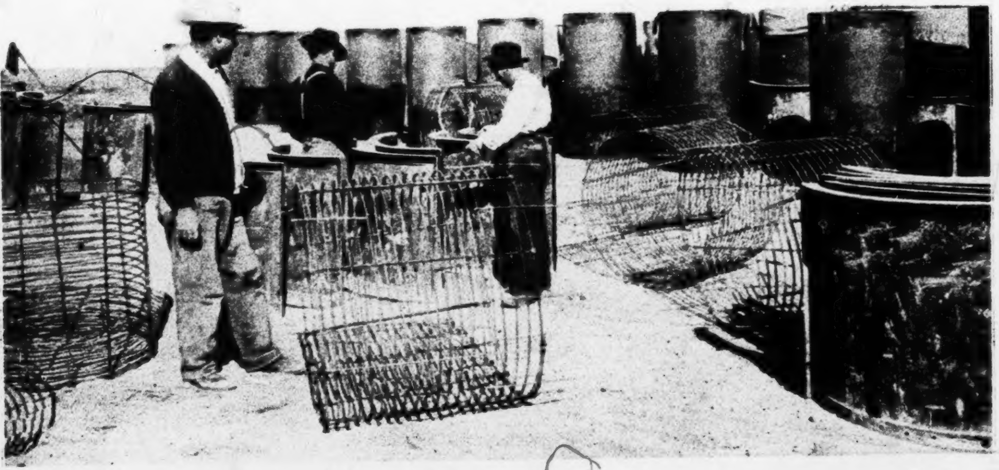
BOISE SCHEME.

(*a*) Deerflat Reservoir, Lower Embankment.

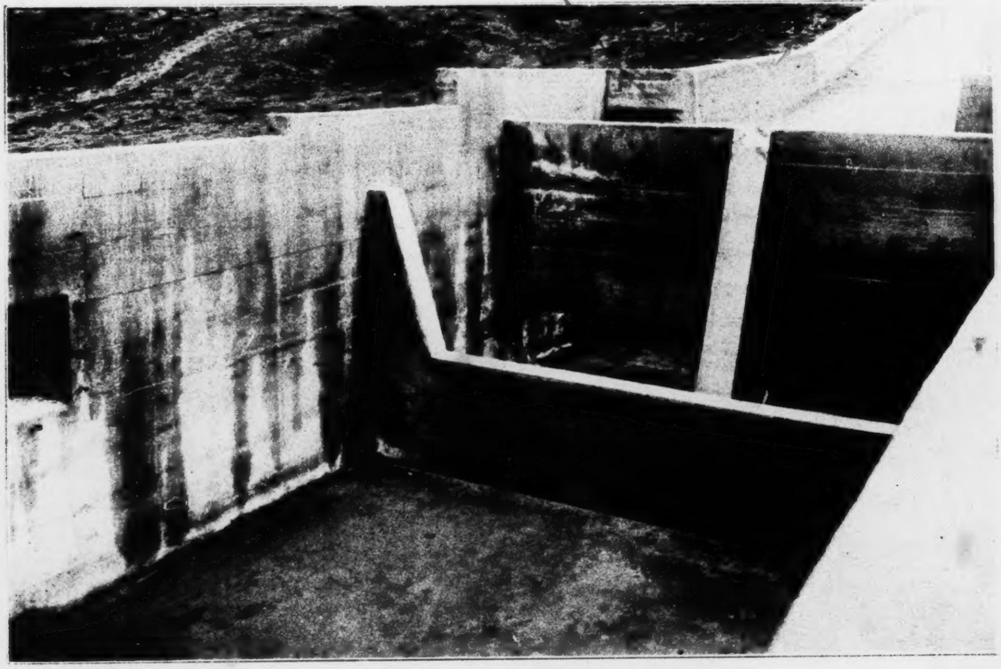
(*b*) Golden Gate Open Shoot-drop.

Plate 6.

BOISE SCHEME.



(*c*) Pipe-making for Syphons.



(*d*) Bottom of Open Shoot-drop on Minor.

and at any point along the cable. It discharges through a swivel-joint into a shoot, the foot of which is also suspended from the cable and can be pulled round to any position within its reach.

Concrete Mixing.

The concrete-mixing plant is at present situated on the edge of the lava ledge on the left bank, at about 170 feet below the proposed crest-level. Here are working two No. 14 "Smith" mixers. Each mixes 1 cubic yard in less than 1¼ minute, making eleven turns per minute. All materials enter the mixer through gates operated by air pressure, and the mixed concrete descends through shoots either direct to the nearer work or into charging-hoppers on the face of the cliff with vertical sliding doors which feed the travelling hoppers on the cables. The cement is weighed, but the other materials are measured by volume. The sand, gravel, and cobbles are obtained from the river bed up-stream of the dam, where a "Stone" dragline excavator with a 70-foot boom and 2½ cubic yard bucket scrapes the material together in the bed of the river and places it in hoppers. These are lifted by a 10-ton derrick with 80-foot boom on the edge of the cliff to a level above the mixers, and are discharged through rotary and sloping screens to the respective sand, gravel, and cobble bins. A large amount of the original excavation for foundations was done by the steam shovel (now in the spillway) and by the upper cables, the material being first dumped on the ledge above the mixers (see plate 4) and afterwards drawn right up to the screens over the mixers, as required, by a "Bagley" dragline grader. All these materials, by passing through rotary and straight screens, are divided into three separate bins, each of from 100 to 180 cubic yards capacity, from which they pass through gates to the mixers. Insufficient sand is obtained from this screening, and additional sand has to be brought by a short railway line. When the excavated material gives out, the lava will be crushed and used for cobbles and stones.

Work is carried on in two shifts of eight hours each, that is, for sixteen hours a day, and these two mixers have turned out as much as 1600 cubic yards per day, the average being 1480 cubic yards, or 38,480 cubic yards for a month of twenty-six days. Each mixer therefore turns out an average of about 46 cubic yards per hour.

Shooting Concrete.

The shoot method of placing concrete is everywhere employed, and there can be no objection on the ground of disintegration where such large quantities are passing so rapidly and regularly. In fact, further mixing goes on in the shoots, which is an advantage. Too steep a slope, however, is not good, and it has been found that an angle of about 25 degrees with the horizontal gives the best results, and that

45 degrees is too steep. The shoots are usually about 1 foot wide and 1½ to 2 feet deep. They are lined with sheet-iron, the bottom separately with curved ⅛-inch iron which wears through very rapidly and has to be renewed every ten days. The shoots are usually in straight lengths with hoppers at bends. The shoot method of depositing concrete is the general method throughout America and is seen in all classes of concrete work, including sky-scraper buildings, where the concrete is first raised by a central lift and then deposited wherever required by radiating adjustable shoots which can reach over great areas. A central lift will probably be employed for the upper part of the dam.

Concrete Forms.

The forms used for the faces of the dam are very simple and are shown in fig. 19. They are 4 feet high and 10 feet wide, and are of 2-inch wood faced with sheet-iron. The concrete is carried up to within 3 inches of the top of the form in place, three steel rods being built into the concrete with eye-pieces just projecting 5 feet 3 inches away from the form. The new form is placed on the old and held in position behind by three cantilevers projecting from the lower form. The cantilevers have a rod attachment at the top with nut adjustment. In front, three long rods, at a slope of 1 on 1½, hook into the eyes of the imbedded rods and are attached to the upper part of the new form by adjustable nuts. The inner rods and adjustments are left in the concrete, and the lower forms are easily removed by unscrewing the outside nuts. The up-stream face being vertical, the forms can be carried up continuously, but down-stream, on account of the slope of the face and the curvature of the dam, the space between the forms gradually opens out as the work rises, and the forms have to be reset at regular intervals.

Cost of Concrete.

An analysis of the cost of a cubic yard of the work is as follows:—

Labour	$0.39
Sand-cement, 357 lb. or .94 barrel	1.47
Gravel, cobbles, and sand	.55
Power (including maintenance)	.07
Forms	.13
Supplies and miscellaneous	.05
Repairs	.08
Depreciation of plant	.17
Plant installation and preparatory expense	.47
Main cableway service	.07
Total	3.45
Add overhead charges (say)	.27
GRAND TOTAL	$3.72 p. cub. yd.

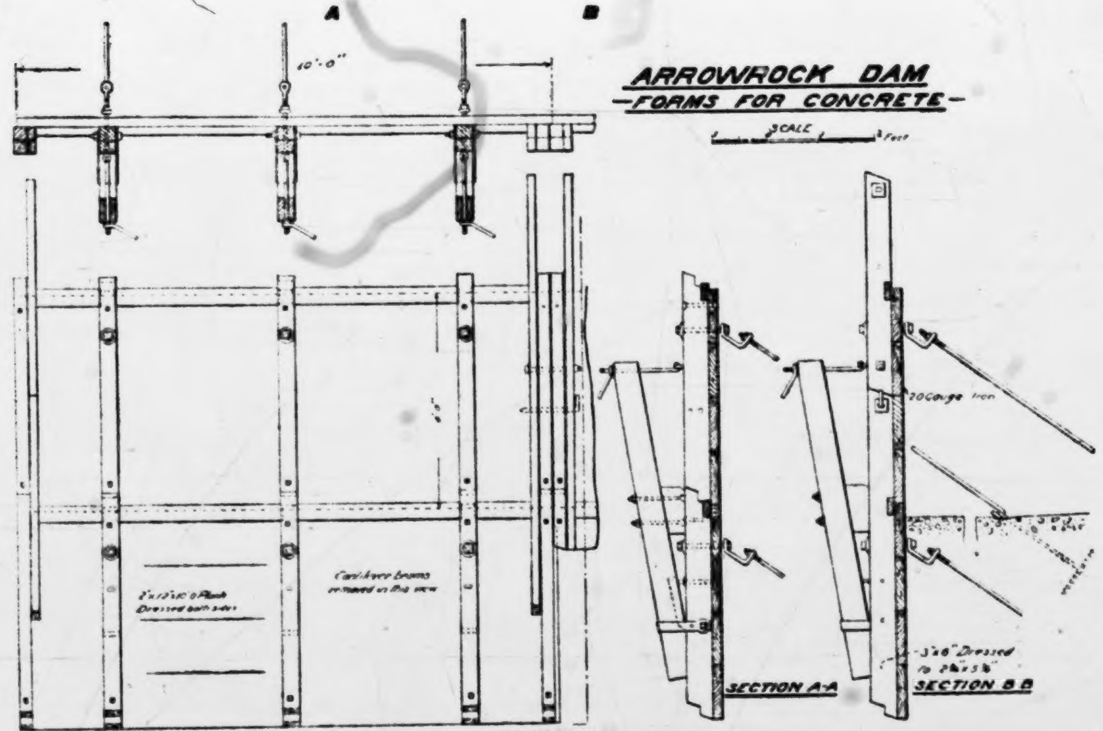

A
B
10'-0"
ARROWROCK DAM
-FORMS FOR CONCRETE-
SCALE
Feet
4'-0"
2"x12"x10'0 Plank
Dressed both sides
Cantilever beams
removed in this view
20 Gauge Iron
3"x6" Dressed
to 2¾"x5⅝"
SECTION A-A
SECTION B-B
A

Fig. 19.

There will be over 530,000 cubic yards of concrete in the dam, and about 20,000 in other works.

River Diversion.

For diverting the river during excavation and construction, a tunnel, 30 feet by 25 feet and 470 feet long, at a slope of 1 in 120, was cut through the granite of the left bank and lined with concrete. It was provided with bell-mouth entrance and exit to increase its capacity.

Coffer-dams were built across the river above and below the dam site, the upper one with crest 37 feet above the river bed. The invert of the tunnel is 6 feet below the river bed. All floods were successfully kept out, and the seepage through the gravel bed into the foundations was very small and always easily kept down by a 4-inch pump. On completion of the dam no use will be made of the tunnel, and it will be concreted up.

Practically all the timber used in the camp and for construction is obtained from a sawmill about seventeen miles higher up the river. This plant is driven by water-power, and was specially erected for the construction of the dam.

Water will be passed down the river channel from the reservoir to the diversion-weir fifteen miles below.

Diversion Weir.

This is 216 feet long, with an additional 30 feet log-way. The height of crest above the original bed is 36 feet, but as the foundation was only a hard compacted gravel, the base of the dam was carried 9 feet into the bed, with an additional cut-off wall 8 feet wide and 6 feet deeper. The up-stream face, therefore, extends to 36 feet above and 15 feet below the original bed, the total height being 51 feet. The crest-width is 12 feet, rounded to 4-foot radius up stream and 10-foot radius down stream. The up-stream face has a slope of 12 on 1 to bed level and then vertical, and the down-stream face a slope of about 1.3 on 1, rounded off at the toe to a radius of 20 feet to bed level. Below that, a timber crib is built for 50 feet to take the shock of falling timber, and the bed is then pitched for a long distance down stream. To prevent seepage under the dam, earth, gravel, and stone were dumped against the up-stream face at a slope of 1 on 3 (12 feet wide at the top), which was carried to 7 feet below crest-level.

Rolling Gate.

An interesting feature of this weir is the rolling gate in the log-way. The log-way is 30 feet wide and its crest is 4 feet below the

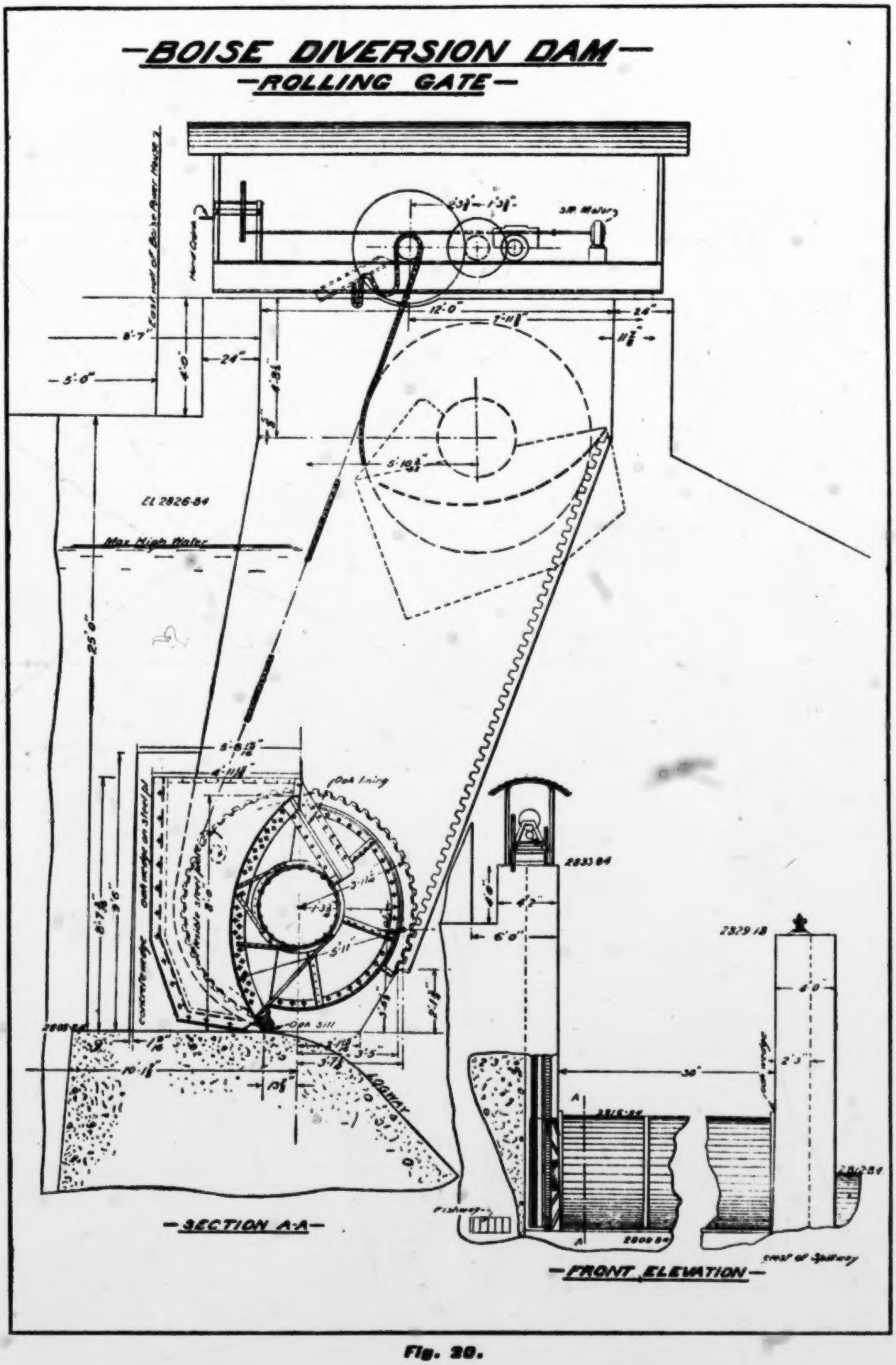

-BOISE DIVERSION DAM-
-ROLLING GATE-
East wall of Boise Power House 2
Hand Crank
3H.P. Motor
12'0"
7'11⅞"
24"
11⅞"
8'7"
4'0"
24"
5'0"
4'8½"
5'10¾"
EL 2826·84
Max High Water
25'0"
5'6"
4'11⅞"
Oak lining
Oak wedge on steel pl
Flexible steel plate
Concrete edge
8'7⅞"
9'6"
3'11"
1'3"
5'11"
Oak Sill
2805·84
10'1⅝"
3'7⅞"
3'5"
LOGWAY
2833·84
6'0"
4'2"
2829·18
4'0"
2'3"
30'
A
2815·84
2806·84
2812·84
Fishway
Crest of Spillway
-SECTION A-A-
-FRONT ELEVATION-

Fig. 20.

weir-crest. The rolling gate is 8 feet high. Fig. 20 shows the manner in which the gate works. The water-face sheath is a segment of a cylinder of 5 feet 11 inches radius. It is attached to a cylinder of 1 foot 3¾ inches radius, which is the axis of the dam, and to each end of this axis, concentric with it, are attached two rims of 3 feet 11¼ inches radius provided with teeth nearly right round. These teeth work in straight racks built into the masonry piers at the ends at a slope of 2⅔ on 1. The gate is raised or lowered by a sprocket chain at one end worked by a rim like the rack rim. The sides are made water-tight by attaching to the gate thin sheets of metal parallel to the pier sides. These are so flexible that the water pressure forces them into close contact with specially prepared surfaces on the pier and leakage is thus prevented. The great advantage of this type, as compared with the ordinary lift gate, apart from the reduction of friction, is that the operating gear is all at one end, and no overhead bridge is required over the gate. This allows of very large spans. In Germany single-span gates have been erected of over 100 feet width. It is also possible, when the head is great, to construct one gate above another, and heads of over 20 feet have been dealt with in this way. The development of this type of gate originated and is greatest in Germany, and the Maschinfabrik Augsburg-Nürnberg firm of Gustavsburg makes a speciality of them.

The power-house for utilizing the power of the fall, as described above, is situated between the log-way and the canal intake gates. These latter are eight in number, each 6 feet high by 5 feet wide, and the sill is 9 feet below the crest of the weir.

Main Canals.

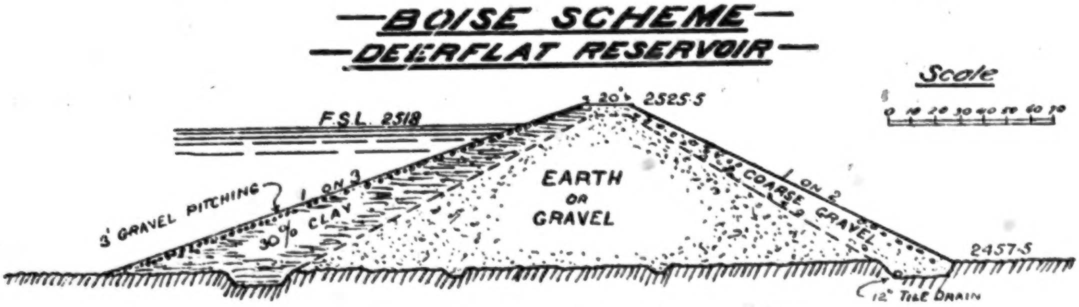
Six miles of the first portion of the canal were designed to have a bed-width of 70 feet, but the canal was at first excavated to a width of only 40 feet. It was found that seepage through the gravel was very great, and, consequently, instead of widening at a later date to the full width of 70 feet, it was decided to line this section with concrete. Kutter's "N" has been found to be .0142 for this lined reach, instead of .025 for the original gravel, and therefore the reduced size of canal was of sufficient capacity when lined. The bottom-width of the lined portion is now 40 feet, the side-slopes 1 on 1½, and the depth 9 feet, the lining being carried to 9 feet 6 inches. The longitudinal fall is 1 in 4000 in the first 3½ miles, and thereafter 1 in 3150. The concrete lining is 4 inches thick, expansion-joints are provided across the canal every 16 feet, and, parallel to the canal, are four expansion-joints, two dividing the bottom into three equal parts, and the other two halfway up the side linings. The upper part of this lined canal is shown in photos C and D, plate 5.

The capacity of the main canal is 2500 cusecs. The slope of 1 in 3150 was found to be much too steep, causing excessive velocity, and to retard this, eight check-drops have been built across the main canal. The main canal, by following the edge of the bench, commands the land which slopes towards the Snake and Boise Rivers, and branches run out along the ridges. The Deerflat reservoir is fed from the main canal at its twenty-sixth mile down the steep slope by utilizing Indian Creek for nine miles and then a graded furrow for eight miles.

The Deerflat Reservoir.

The Deerflat reservoir is situated in the middle of the lands and commands only a portion of them at a lower level. A natural valley was dammed by three embankments, the dimensions of which are as follows:—

	Max. height.	Length of crest.	Cub. yds.
No. 1	70 ft.	4000 ft.	1,170,200
No. 2	40 ft.	7200 ft.	1,130,800
No. 3	16 ft.	950 ft.	25,500



Maximum Cross Section of Dam

Fig. 21.

The type of cross-section is shown on fig. 21 and photo A, plate 6. A large proportion of gravel is used and the up-stream pitching is simply loose small gravel. It was placed at a slope of 1 on 3, but was washed down to a flatter slope.

This reservoir floods 9835 acres, and has an available capacity of 177,600 acre-feet. The main distributing canal from the reservoir starts from the left bank of the lower dam, doubles round the spur on the left, and runs back along the Snake River, irrigating the lands sloping steeply down to this river.

Golden Gate Drop.

Before doubling round the spur, a shoot-drop of 34 feet is provided (the Golden Gate drop), which supplies a big branch running down

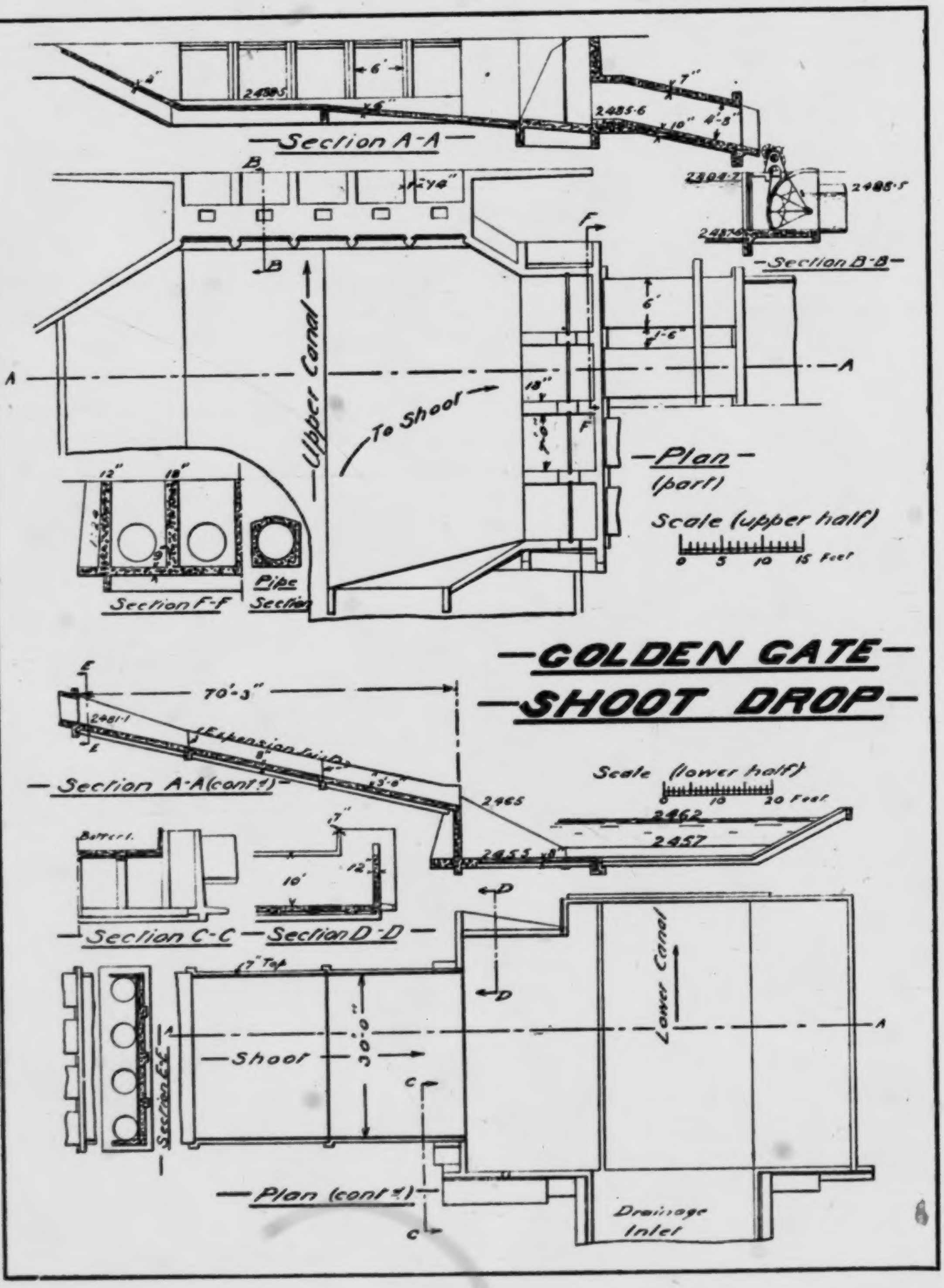

Section A-A
6'
2489.5
2485·6
7"
10"
4'-8"
2484.7
2488.5
2487.6
Section B-B
1'-7½"
B
F
6'
1'-6"
18"
A
Upper Canal
To Shoot
Plan (part)
Scale (upper half)
0 5 10 15 Feet
12"
18"
Section F-F
Pipe Section
GOLDEN GATE
SHOOT DROP
E
70'-3"
2481·1
Expansion Joints
Section A-A (cont'd)
Scale (lower half)
0 10 20 Feet
2465
2462
2457
2455.5
Batter
Section C-C
7"
10'
12"
Section D-D
D
7" Top
Shoot
30'-0"
C
Lower Canal
Section E-E
Plan (cont'd)
Drainage Inlet

Fig. 22.

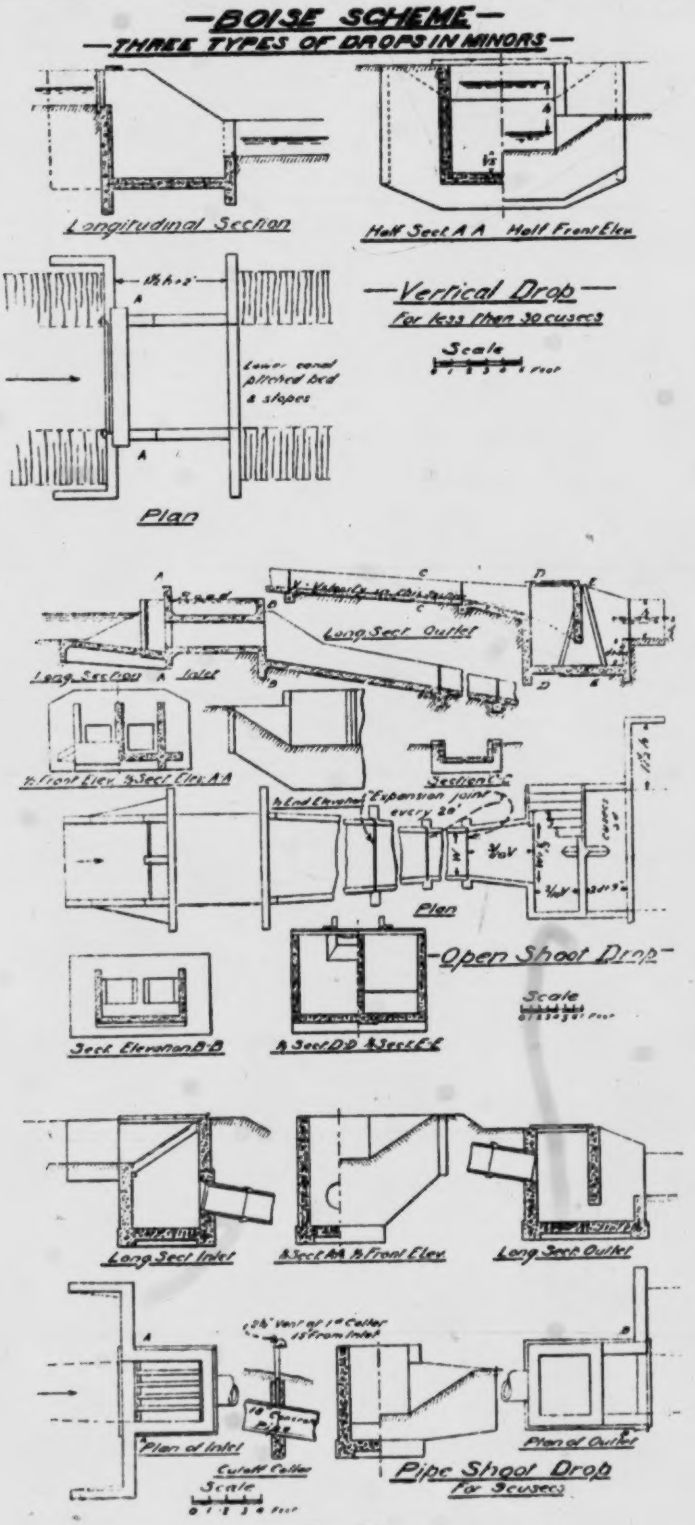

—BOISE SCHEME—
—THREE TYPES OF DROPS IN MINORS—
Longitudinal Section
Half Sect A A Half Front Elev
1½ h+2'
A
A
Lower canal pitched bed & slopes
Plan
—Vertical Drop—
For less than 30 cusecs
Scale
0 1 2 3 4 5 Feet
A
C
D
E
Long. Section A Inlet
Long. Sect Outlet
B
C
D
E
½ Front Elev ½ Sect Elev A-A
Section C-C
½ End Elevation
Expansion joint every 20'
¾₀V
¼₀V
11½ A
Plan
Sect Elevation B-B
½ Sect D-D ½ Sect E-E
—Open Shoot Drop—
Scale
0 1 2 3 4 5 6 Feet
Long Sect Inlet
½ Sect AA ½ Front Elev
Long Sect Outlet
2½" Vent at 1st Collar 15' from Inlet
A
B
18" Concrete Pipe
Plan of Inlet
Cutoff Collar
Plan of Outlet
Pipe Shoot Drop
For 9 cusecs
Scale
0 1 2 3 4 Feet

Fig. 23.

along the spur between the two rivers. The Golden Gate drop is interesting, as it is built on soft fine sand and drops about 400 cusecs through 34 feet. This is shown in photo B, plate 6, and details are given in fig. 22. It is a reinforced concrete structure. Across the higher canal are six radial gates, each of 6-foot span. Four 56-inch diameter pipes lead to the shoot, which is square to both canals, 85 feet long, and at a slope of about 1 on 4. At the bottom is a water cushion, 2 feet below canal bed, and the lower canal runs on parallel to the upper one, the soft sandy banks being protected for some distance by stone and bush pitching.

Flumes, Pipes, Drops, etc.

On account of the hilly nature and steep slopes of the upper part of the area irrigated by the Government scheme, a very large number of flumes, pipes, drops, and shoots is required. For flumes, the Maginnis, or improved type of semi-circular iron trough, is largely used. Expansion-joints are always provided, especially at the ends, and the end sections are usually tapering or of larger size than the rest. An enormous length of pipes is also required to carry distributary waters through deep valleys to isolated high parts. The more recently constructed are usually of reinforced concrete made at the site. Photo C, plate 6, shows the type of reinforcement and moulds. The reinforcing wire is spirally wound with a special spacing device. The top rings of the inner moulds and some made pipes are seen in the background, and the sections of the outer mould are in the foreground, six sections going to each mould. It should be noted that near the entrance of all pipe lines, especially with steep slope, a vent pipe is provided to remedy the hammering due to air sucked in at entrance.

Drop structures are (1) for small drops, vertical; (2) for bigger drops: (*a*) open shoots where the slope is uniform; (*b*) pipe-shoots through ground of varying slope. These three types are shown on fig. 23. The vertical drop has a water-cushion of depth equal to the cube root of the height of drop, and of length equal to 1½ height + 2 feet. A few drops are also built with openings V-shaped instead of rectangular.

At the bottom ends of both the open and pipe shoots water-cushion chambers are provided, and in them baffle-walls, against which the water discharges. Photo D, plate 6, shows the bottom end of one of the open shoots and also a weir to steady the flow before entering a pipe below. This is a type of the neat reinforced concrete structures which abound on this project.

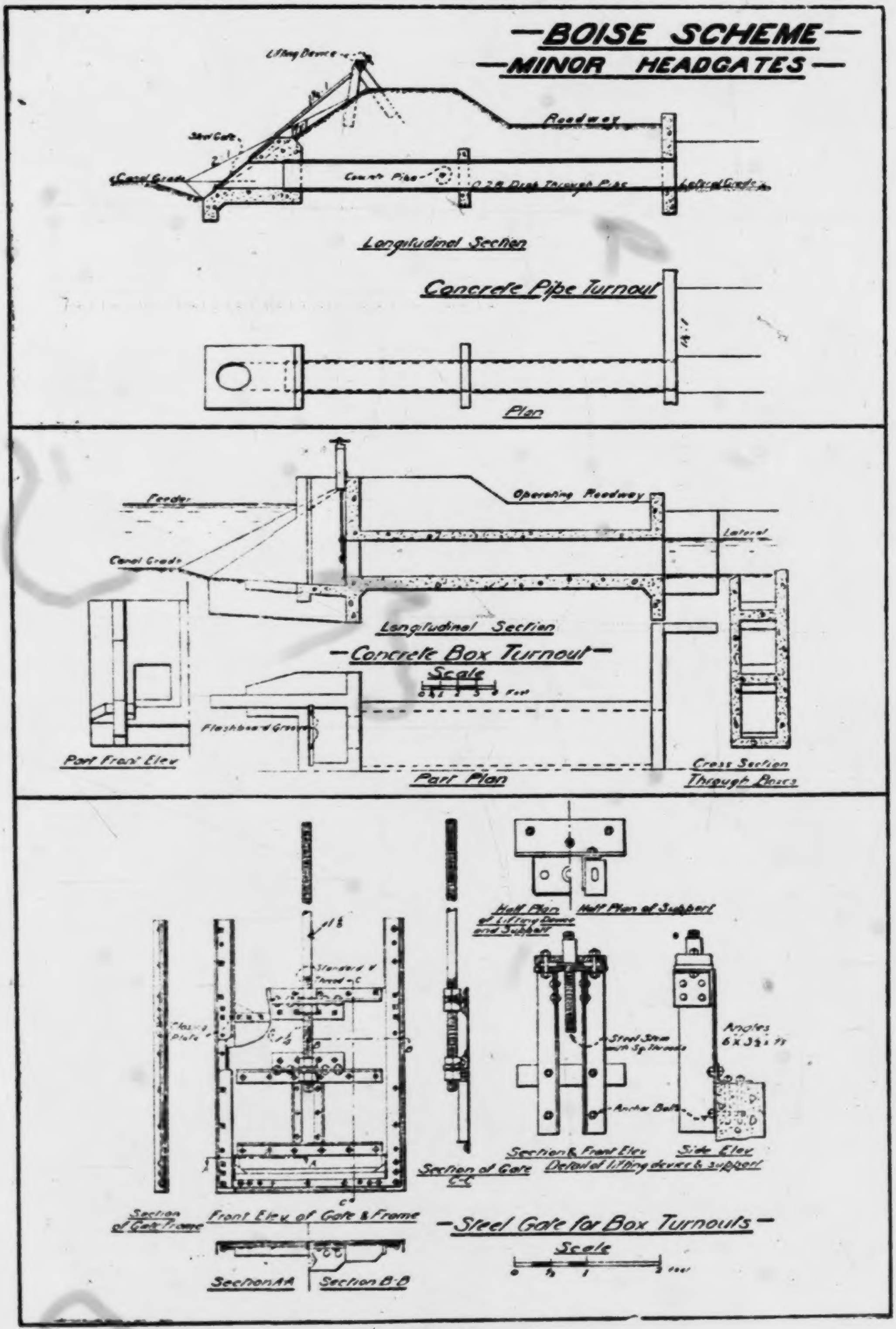

—BOISE SCHEME—
—MINOR HEADGATES—
Lifting Device
Steel Gate
Canal Grade
Roadway
Concrete Pipe
0.2 ft Drop Through Pipe
Lateral Grade
Longitudinal Section
Concrete Pipe Turnout
Plan
Feeder
Operating Roadway
Lateral
Canal Grade
Longitudinal Section
—Concrete Box Turnout—
Scale
Feet
Flashboard Groove
Part Front Elev
Part Plan
Cross Section Through Boxes
Half Plan of Lifting Device and Support
Half Plan of Support
Standard V Thread
Closing Plate
Steel Stem with Sq. Threads
Angles 6 x 3½
Anchor Bolts
Section of Gate Frame
Front Elev of Gate & Frame
Section of Gate C-C
Section & Front Elev
Side Elev
Detail of lifting device & support
—Steel Gate for Box Turnouts—
Scale
0 ½ 1 2 feet
Section A-A
Section B-B

Fig. 24.

Two types of head-gates for minors are shown in fig. 24, the one for larger minors with vertical gate and box-culvert under the road, and the other with gate parallel to the side slope and with pipe-culvert. It should be noticed that the invert is always lower than the canal-bed, and the pipe has a slope.

Soils, Slopes, Methods of Irrigating and Drainage.

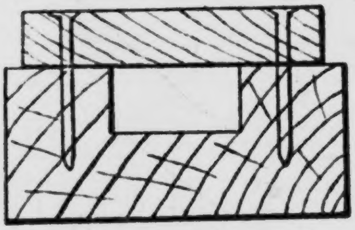
The area irrigated forms a triangular patch between the Boise and Snake Rivers just before their junction—what would in India be called a "doaba." The highest ridge running down between these two rivers is nearer the Snake River.

The soils vary from a clayey loam to a light sand or sandy loam, a large area consisting of volcanic ash in a very fine state of division. The longitudinal slope down the Boise River is about 14 feet per mile, and the portion bordering it—several miles wide—for a great distance slopes the same way, the contours running roughly square to the river. This portion is therefore very easily irrigated, and all the old canals were for this reason confined to the part bordering the Boise River.

"Corrugation" Irrigation.

The rest of the "doaba," containing the central parts and those bordering the Snake River, is higher and more undulating, and has generally much steeper slopes. Here lie most of the new lands for which the Government scheme was carried out, and not only was the construction on this account much more expensive than for the older schemes, but the actual application of water to the lands is not nearly such an easy matter. The slope here is as much as 200 feet or more per mile, and the soil is often of a very fine sandy nature. Whereas the method of surface flow between borders answers very well in most of the older and flatter tracts, other methods have to be adopted on the steep and sandy soils which would wash away or irrigate very imperfectly if the water were simply turned down the slope. The method adopted is known as the "corrugation" method of irrigating, and consists of a series of small parallel furrows running down the slope of the land to be irrigated (see plate 7, photo A). A very small stream is run down each furrow, and in this way the whole land is saturated. This method is not a mere experimental fad or of use for vegetables only, but is actually employed over thousands of acres of lucerne and other crops, and is the most common method on a large number of other big schemes along the Snake River, where the conditions are similar as to steep slopes and light soil. The furrows are usually from 2 to 3 feet apart and about 4 inches deep. Special furrowing machines drawn by animals are made of wood or steel, which make two or three furrows at a time. The steel machines have sharp-cutting edges, and can remake furrows in old lucerne fields (see plate 7, B). At the top of the field the farmer's furrow runs along the contour. Immediately below this furrow another furrow is made which is divided into sections, each fed from the upper furrow by a small box through the wall between the two furrows.

This latter contour furrow supplies each of the corrugations through small wooden pipes known as "spiles," which pass through the lower wall and discharge into the small corrugations. Fig. 25 shows a section of one of these "spiles." They are made by the farmers by cutting up grooved planks into suitable lengths, usually 2 feet, and then simply nailing another plank over the open side. This gives a pipe of about ¾ inch by ⅜ inch, and through this the small supply to each corrugation is passed.



Cross Section of
"Spile" for Corrugations
Full Size

Fig. 25.

Drainage.

As on the Shoshone scheme, seepage and alkali have appeared on this scheme, in spite of the gravel beds which underlie a large part of the area. As we might expect, the area which has been first affected is that lying below the Deerflat reservoir between it and the Boise River. The seepage from the reservoir must be very great. A drain constructed immediately below one of the banks discharges about 4 cusecs. Another deep drain, a short distance below the dam, although not much more than a mile in length, discharges as much as 16 cusecs. Not only are the low-lying lands along the creeks which traverse this area affected, but even the high ridges between, and I noticed in one place, where two creeks ran parallel and less than one mile apart, the ground between (which was 40 feet higher) was so affected that orchards there died off.

A number of open drains have been constructed, especially through swamps. A large portion of the area affected lies in the Pioneer irrigation district, and, at the same time as they contracted to pay $560,000 to Government for a share in Arrowrock storage, they contracted to pay $300,000 for the construction of drains to remedy seepage and alkali.

Crops. Cereals and lucerne are the two chief crops, and together cover (nearly equally) about 80 per cent. of the irrigated area. Pasture, orchards, and vegetables occupy most of the rest and in the order named, apples and potatoes being the chief products under the latter two heads.

Wheat gives an average return of about 19 bushels per acre, and sells at 60 cents per bushel. Lucerne gives an average return of 3¾ tons per acre for about three cuttings, and is sold at $4½ per ton, which is a lower value than we have noted in the three previous schemes, probably owing to overproduction in proportion to the stock on the scheme. Potatoes produce about 100 bushels to the acre, and sell at about 50 cents per bushel—a very profitable crop. Apples form the greater proportion of the orchards, and the chief varieties grown are "Jonathan" and "Rome Beauty."

Settlement. The area under the scheme embraces nearly all the land in the "doaba" between the Snake and Boise Rivers, the chief exception being the strip of low lands along the Boise River which was easily irrigated by the older canals, and therefore obtained good water-rights by appropriation. The total irrigable area which it is contemplated will derive advantage from the scheme is 243,000 acres; but of this extent 36,000 acres are doubtful, lying in irrigation districts and possibly not requiring assistance. We may therefore take the total area at approximately 200,000 acres. Of this roughly two-thirds was privately owned and one-third entered by settlers under the new scheme. Of the privately owned land by far the largest part lies in the two irrigation districts, the Nampa-Meridian and the Pioneer. These two districts were formed before the Government scheme was started.

The Ridenbauch canal served the former and the Phyllis and Caldwell canals the latter. These canals were not of large enough capacity for the whole areas under them; moreover, the water-right appropriations were too late for any supply in the latter part of summer and no storage was provided. The Government having sufficient, though later, water-right appropriations and also the Deerflat and Arrowrock storage, has entered into contracts with these two districts to supply them with flood and stored water and to carry out certain works, such as enlarging their furrows and constructing drains. The Pioneer district, for instance, pays $560,000 to Government for such share of the storage of Arrowrock as this sum bears to the whole cost of Arrowrock, and a further sum of $300,000 for drainage works to be carried out in their district by Government. With this large proportion of privately owned land, much of it already served by existing works, it was obviously impossible for Government to proceed in the same simple way as described in the three previous schemes, which is to fix a uniform rate per acre as a building charge on all who benefit by the scheme, and thereafter a uniform annual maintenance rate. The method adopted here has been to make only one charge in the form of an annual water-rent for volume of water used. In 1912 and 1913 the charges were 60 cents per acre-foot for stored water out of the Deerflat reservoir, and 40 cents for flood water during the irrigation period, whether direct or out of Deerflat reservoir, so long as the river flow was sufficient to satisfy Government's appropriation right for direct flow. These rates have, however, been as high as $1.25 and 75 cents respectively. Only a portion of the lands which are low-lying can at present get stored water from the Deerflat reservoir, but when the Arrowrock dam is completed stored water will be available for all the lands. No water is supplied by Government to any one who has not become a member of the Boise Water-Users' Association. By joining this each user acquires as an individual water-right a portion of the whole water-rights of Government in proportion to his land and the shares he takes up, and obtains priority according to date of joining. This is the inducement to bring all under a uniform organization. Before any water is delivered to an individual he has to sign each year an official application in the form of a promissory note due at the end of the year.

Practically all of the new land was taken up by settlers at an early date. During 1913 about 66,000 acres were irrigated—only one-third of the 200,000. The cost of the completed scheme will probably be $70 per acre.

Distribution of Water, Duty, and Maintenance.

All water is, as we have seen, sold by volume, and consequently measurement has to be much more exact than in the three previous schemes. In the case of delivery to irrigation districts the water delivered to the district canal is measured in bulk, and the districts are responsible for allocation to individuals. In all other cases each individual has a measuring device at the head of his furrow. This is usually a free-fall trapezoidal weir or, if the fall is insufficient, a drowned weir, or preferably a drowned orifice. The farmers are now educated up to judging roughly the size of a stream in cusecs, and can read and check their own weirs. In fact discharge-tables for weirs are often to be seen on the back of advertisement cards and pamphlets.

The application in 1912 was 1.7 foot for the upper lands, and 2.33 for the lower lands measured at the fields, and more than double this at the canal intakes. The average loss in the canals is estimated to have been a little over one-half cubic foot per day per square foot of wetted area of canals, though in gravel parts it was much more.

A large number of observations and experiments on duty have been made in the Boise valley on a number of separate canal systems. The average application measured at the intakes was found to be a little over 4 feet, of which less than half reached the lands. More than half of the water is applied during the months of June and July.

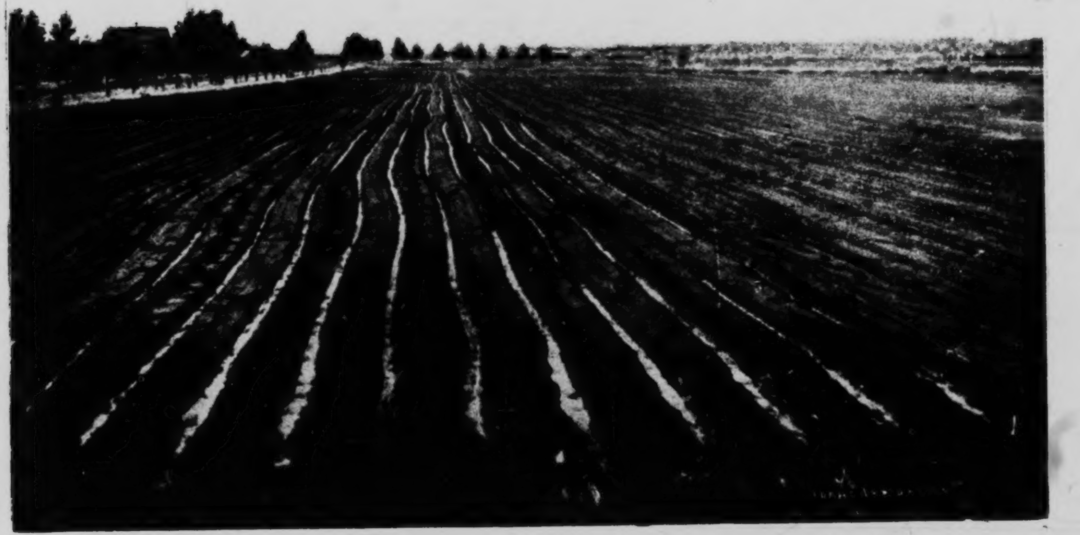
A large number of experiments have shown that wheat gives a maximum return of grain per acre, with a total watering of 1 foot 6 inches per season—about 1000 lb. per acre-foot of water applied. Any greater supply gave a less total return per acre, and half the above also gave a less return, but at the much higher rate of 2500 lb. per acre-foot applied. During the growing period the rainfall varied from 1½ inch to 4 inches. These results show that, under these conditions, it does not help in the least to apply more than 1½ foot, and that the maximum return from a given quantity of water is obtained by spreading it over the greatest possible area.

With regard to lucerne, the average applied in a season on compact soils is about 2½ feet in four or five waterings, and the yield increases with increased application up to a limit somewhere over 5 feet. Open sandy soils require at least twice as much. The irrigating season for lucerne lasts from 1st May to 15th September, and the demand rises to a maximum in June and July.

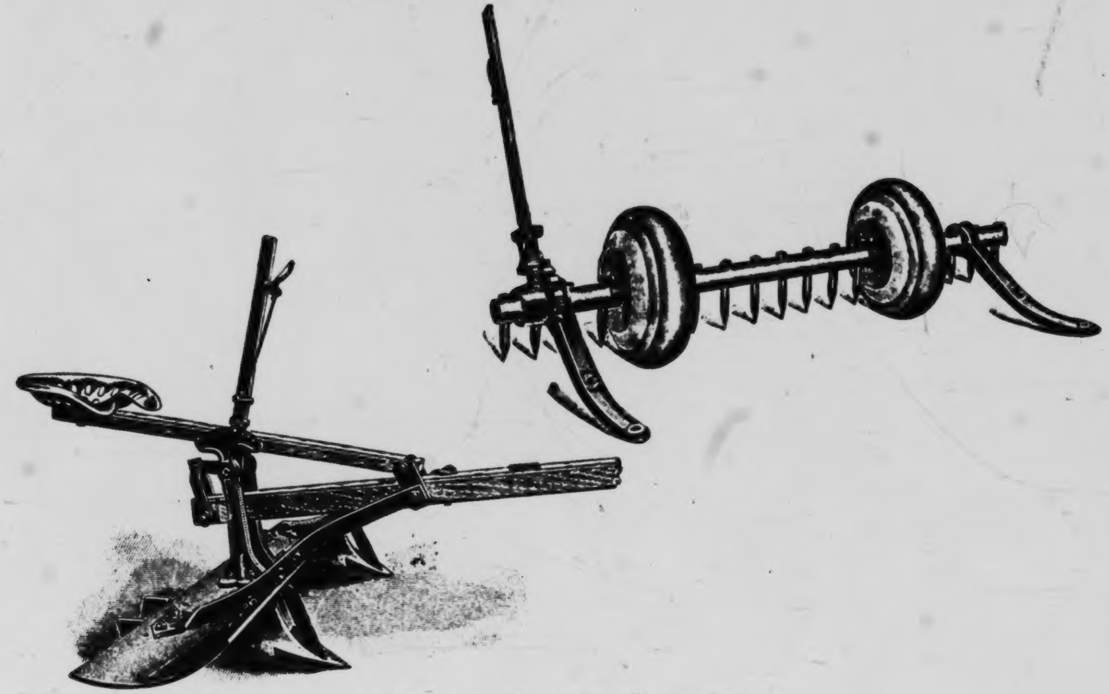
The usual stream put on a field by surface flow between borders is 1 cusec or less, and experiments have shown that, especially in open soils, the bigger the flow—so long as the soil will stand it—and (comparing beds from 200 feet to 2000 feet in length) the shorter the bed, the more economically is the water employed.

The cost for operation and maintenance in 1912 was about $1½ per acre irrigated. Clearance of weeds and moss forms a large part

TWIN FALLS SOUTH SCHEME.



(*a*) "Corrugation" method of Irrigating.



(*b*) Instrument for making Corrugations.

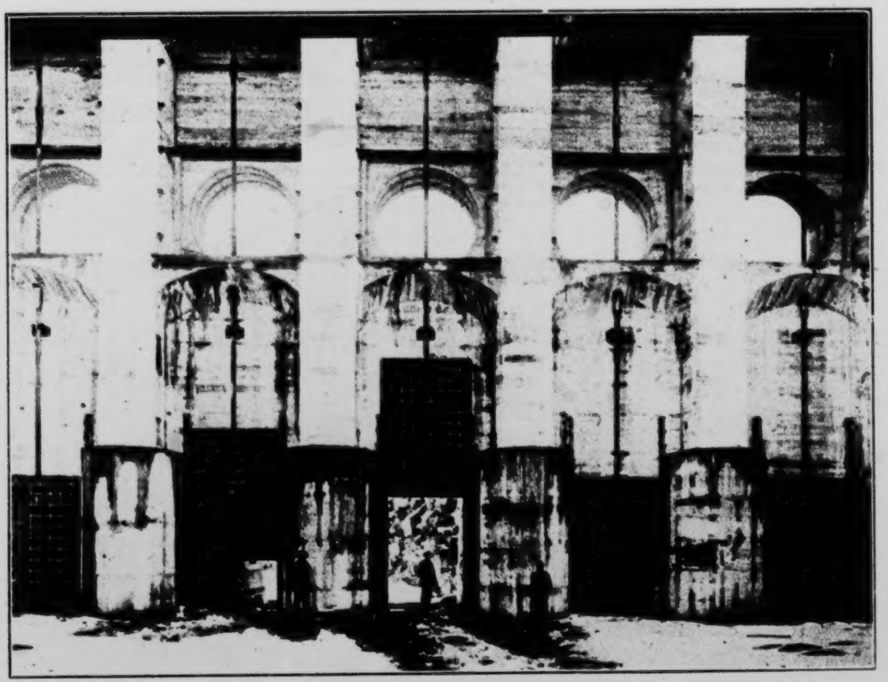
Plate 7.

MINIDOKA SCHEME.

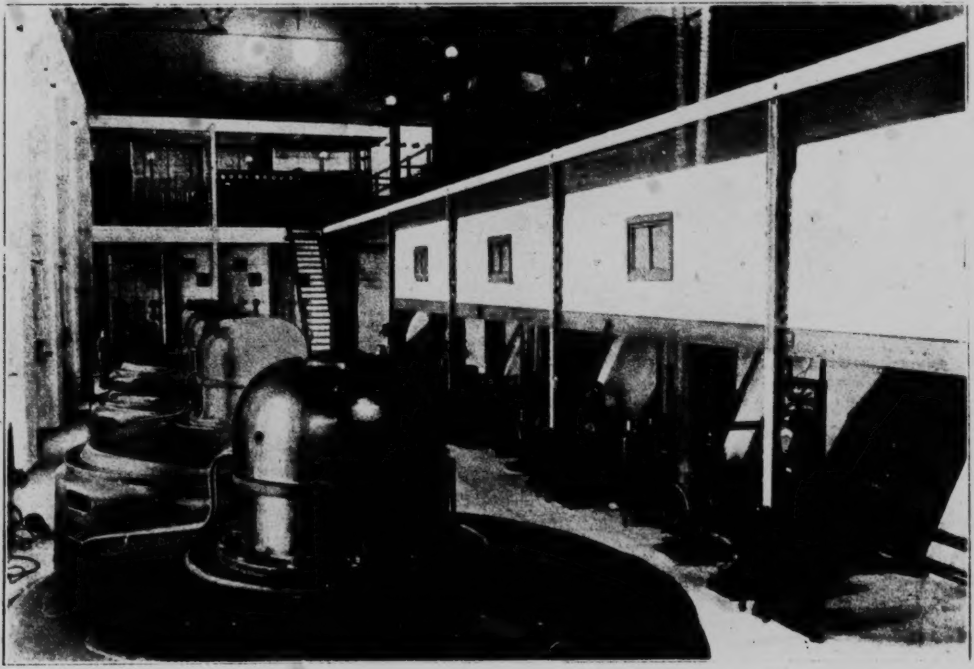
(*c*) Main Canal on North side.

(*d*) Original state of Land with Sage-bush on left, Lucerne Field on right.

MINIDOKA SCHEME.



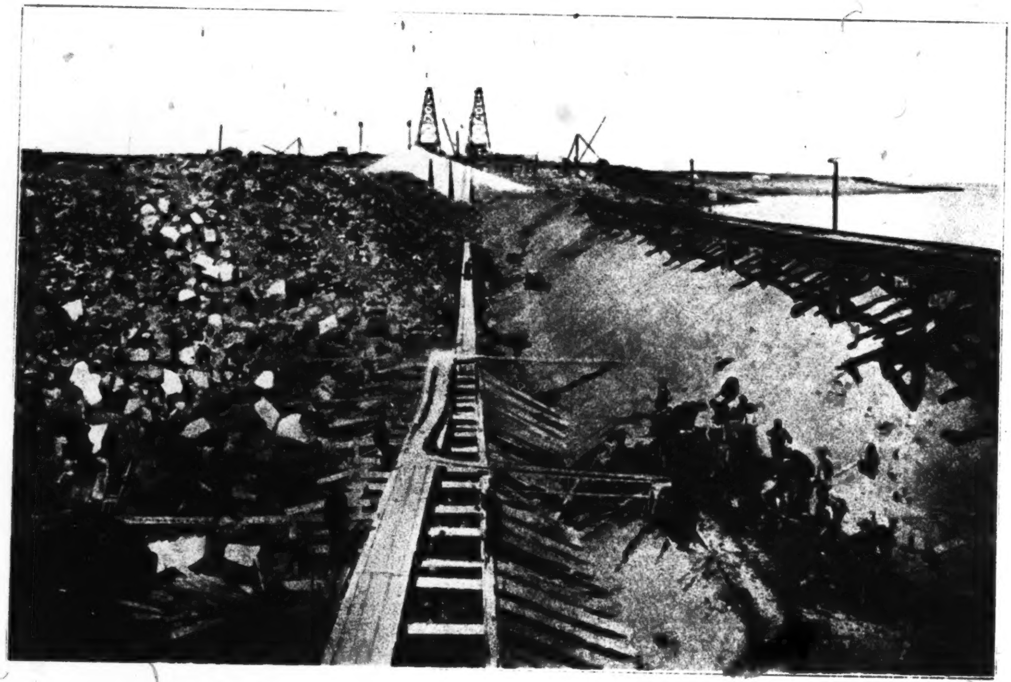
(*a*) Sluice-gates and Penstock Openings before building of Power-house.



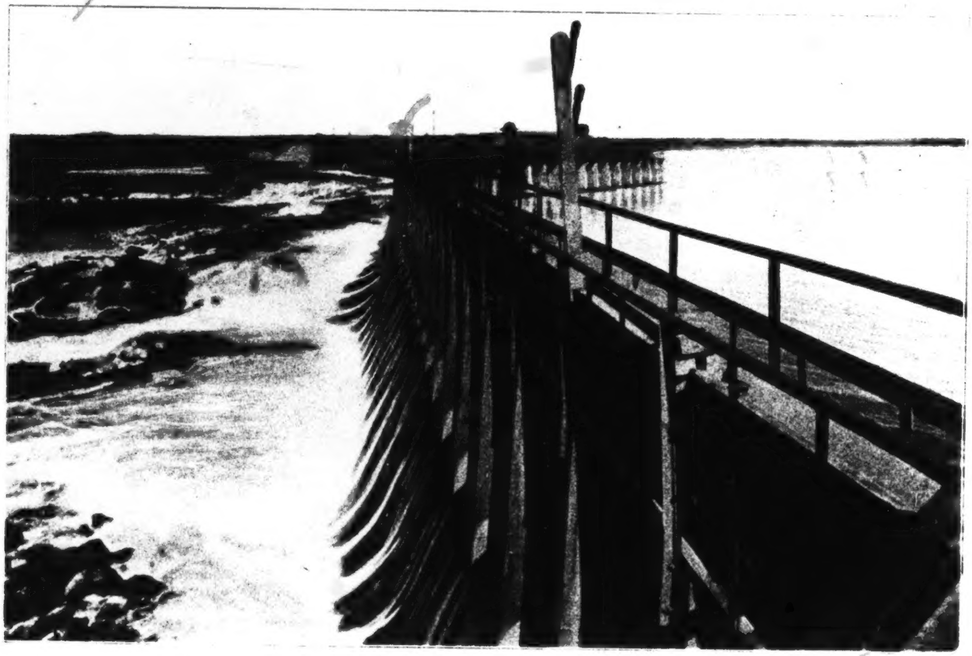
(*b*) Inside of Power-house.

Plate 8.

MINIDOKA SCHEME.



(c) Rock-fill Dam from end of Overflow Weir during construction of Core-wall.



(*d*) Part of Overflow Weir.

of the maintenance cost. Moss gives much trouble, especially in midsummer, when it grows at an extraordinary rate in open places, reducing the discharge of small canals by half in a short time. Velocity and depth of water do not have much influence on its growth, which seems to depend on warmth and light. In dark culverts, or where masonry is painted black, it does not grow. The most effective instrument for cutting it is the Ziemsens weed-cutting saw (Ascrert Bros., West Bend, Wisconsin). This saw has been tried at Douglas, Cape Province, and has given great satisfaction there. Weighted chains and disk-harrows are also used successfully. Other weeds on the banks, such as Russian thistle, also give trouble, and experiments have been made to find out if they can be kept down by sowing a useful mastering crop. Rye has been found to answer best, and is very cheap. Sown in the autumn, it comes up before the weeds in spring and chokes them down.

CHAPTER V

THREE SNAKE RIVER SCHEMES

THE MINIDOKA SCHEME

THE Minidoka and Twin Falls schemes, to be now described, take their waters from the Snake River, and a few of the peculiar features of this great river will first be pointed out.

The north and south forks of the river are the most eastern sources and rise in the neighbourhood of the Yellowstone Park. The south fork is the greatest feeder and has its origin in Jackson Lake high up in the Rocky Mountains and surrounded by peaks 12,000 feet high. Melting snows thus form the chief source of supply to the Snake, but, as we shall see, not the only source, for at several points throughout its course the flow is augmented by some of the most wonderful underground sources in the world.

The two forks, after following very tortuous courses, join about sixty miles due west of Jackson Lake. The river then runs south-west for about forty miles to Blackfoot, with a good fall through irrigable

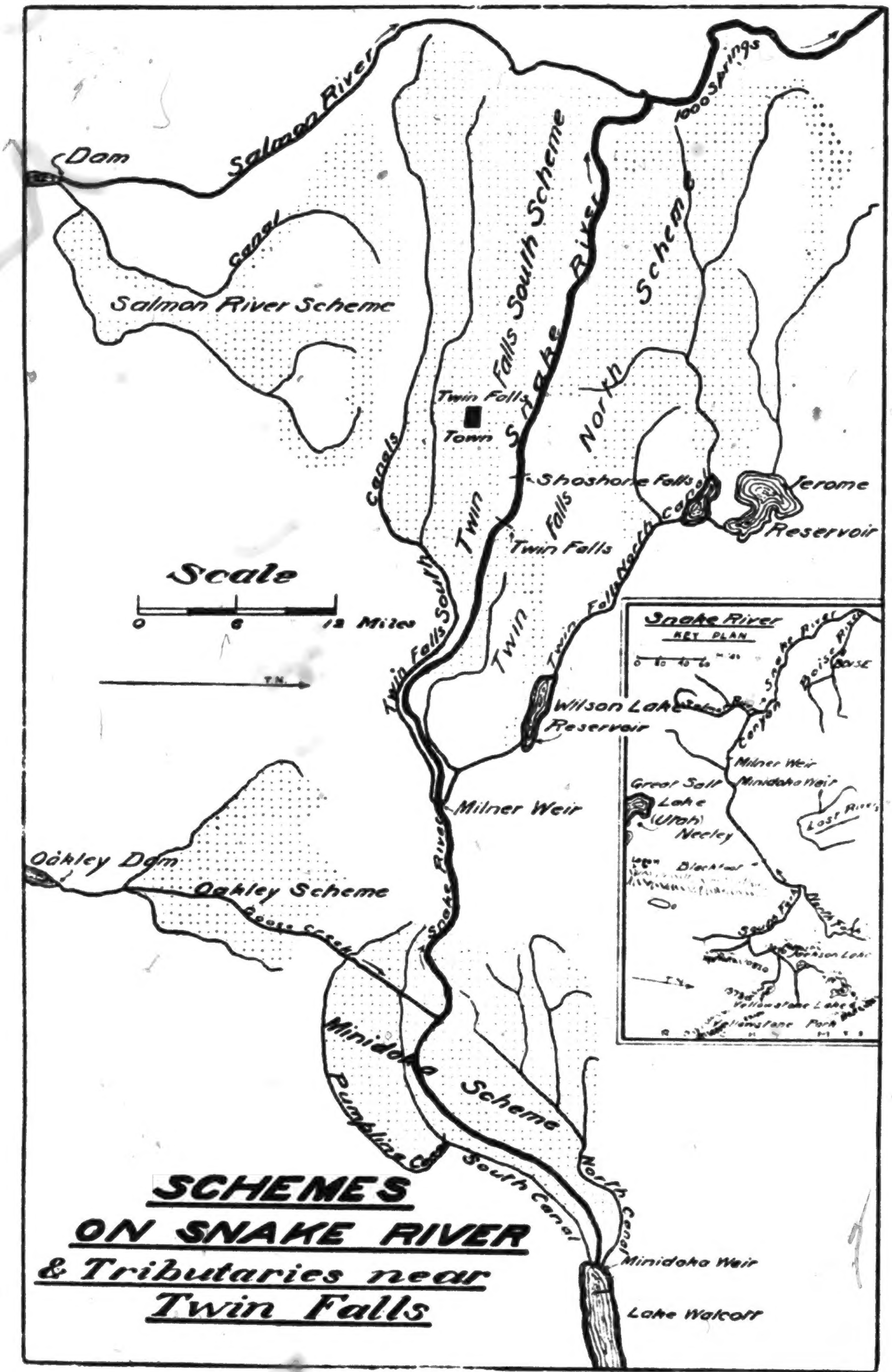

Salmon River
Dam
Canal
Salmon River Scheme
Canals
Twin Falls South Scheme
Snake River
Twin Falls Town
Twin Falls South
Twin Falls North Scheme
1000 Springs
Shoshone Falls
Twin Falls North Canal
Jerome
Reservoir
Twin Falls
Wilson Lake Reservoir
Milner Weir
Scale
0
6
12 Miles
T.N.
Oakley Dam
Oakley Scheme
Goose Creek
Snake River
Minidoka Scheme
Pumpline Canal
South Canal
North Canal
Minidoka Weir
Lake Walcott
Snake River
KEY PLAN
0
20
40
60
Miles
Snake River
Boise River
Boise
Canyon
Milner Weir
Minidoka Weir
Great Salt Lake (Utah)
Neeley
Blackfoot
Lost River
South Fork
North Fork
Jackson Lake
Yellowstone Lake
Yellowstone Park
SCHEMES ON SNAKE RIVER & Tributaries near Twin Falls

Fig. 28.

ground. About fifty canals take out above Blackfoot, and in the dry period in August they absorb the whole flow. But in a most extraordinary way the flow is increased again in the next forty miles to American Falls (close to Neeley) by about 2500 cusecs. As explained in the Boise scheme, the greater part of southern Idaho is covered with lava sheets which in general are very porous. Just north of this reach the famous Big Lost River absolutely disappears below ground in this formation. The increased flow of the Snake is due to the reappearance of this water as well as to the return of the waters which have seeped away in the irrigated parts above and been brought to light again by the impervious dykes which cross the river as at American Falls. Above Neeley there are about 800,000 acres of irrigable ground, of which 40 per cent. is already irrigated. From Neeley to the Minidoka weir is thirty-two miles and very little water is taken out or added in this length. In the next thirty-five miles, however, are the two big weirs for the three irrigation schemes—the Minidoka and the Twin Falls North and South schemes—which together are designed for a total area of over half a million acres.

Up to the site of the lower weir at Milner, the Snake valley has a gentle slope with no great falls, and the bed of the river is not much lower than the surrounding country. At Milner, however, the nature of the river changes entirely and very suddenly. Just below the weir it plunges into a deep and narrow canyon in which it continues for sixty miles several hundred feet below the surrounding country. The total fall in the sixty miles is 1500 feet and about half of this is in vertical drops of 50 to 210 feet, the most notable drops being the Twin Falls with a vertical drop of 187 feet, and, five miles further down, the Shoshone Falls with a vertical drop of 210 feet. The power possibilities of these falls are enormous and have already been partly developed.

This region is therefore unique on account of its great possibilities for both irrigation and power, and the schemes in the neighbourhood should be visited by all interested in such development.

Although below the schemes to be described, reference should be made to the wonderful "Thousand Springs" which enter the lower part of the canyon from the north. From beneath the lava beds innumerable springs burst out high up on the side of the canyon and drop some 100 to 200 feet to the river below. The total volume poured out is extraordinary, and amounts to about 4500 cusecs. The origin of this water is uncertain, but it probably comes from some of the lost rivers through the porous and seamed lava beds.

Of the three schemes to be described, the Twin Falls South is the largest and the oldest. It has, therefore, the first water-right appropriation, amounting to 3000 cusecs. The Minidoka scheme has next water-right, and the Twin Falls North the last.

Gaugings taken at Neeley, which is thirty-two miles above the Minidoka weir, gave an average annual run-off of 6,620,000 acre-feet, a miximum of 8,900,000, and a minimum of 3,830,000 acre-feet. Not much water is added or taken out between Neeley and Minidoka weir, so that these figures give a fair idea of the annual flow available at Minidoka. The monthly average discharge in cusecs at Neeley for 1911 (a year a little above the average) is as follows:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Cusecs ...	5880	6920	7500	8000	18,400	29,700	12,700	3030	5140	6300	6780	6840
							Plus	2780*	500*			
								5810	5640			

Total ... 7,270,000 acre-feet,
of which 202,480 „ are from Lake Jackson storage.

For about forty days during August and September, the mean discharge is usually low, between 2000 and 3000 cusecs. The maximum discharge in 1911 was 37,600 cusecs in June. In 1909 it was 41,100, and in 1896 it was 53,100. The drainage area above Neeley is 16,000 square miles.

From these figures it will be seen that the low-water flow is sufficient for the Twin Falls South scheme with its earlier appropriation, but that storage is necessary for the other two schemes. This has been provided by the Federal Government for the Minidoka scheme in Jackson Lake at the source of the Snake, and portion of this storage has at times been sold to the Twin Falls North scheme.

The Federal Government is interested in and has helped all three schemes, the Minidoka scheme more directly under the Reclamation Act, and the other two under the Carey Act. The Salmon River and Oakley schemes, also Carey Act schemes, are on tributaries which enter the Snake from the south, and the lands irrigated by them lie just south of the Minidoka and Twin Falls schemes. These two schemes will also be briefly described. They are particularly interesting, as they depend entirely on storage of the whole flow of small drainage areas.

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* Stored water from Jackson Lake.

THE MINIDOKA SCHEME

(United States Reclamation Service, Idaho)

Locality.

The irrigable lands on this scheme lie on both sids of the Snake River, stretched along about twenty-five miles of its length and at a very small height above the water-surface of the river. In this respect it differs from the Twin Falls schemes which border on the deep canyon and are therefore several hundred feet above the river water-surface. The river divides the irrigable lands into two portions nearly equal in size but very different in nature. The lands on the right bank form a compact flat or pocket of sandy alluvial soil—very low and very level. Those on the left bank have a heavier soil, are steeper and higher, the upper parts requiring pumping.

The mean elevation of the lands is about 4200 feet. The rainfall is 12 inches, and the range of temperature from −11° to 100° F., the irrigating season being similar to that of Boise.

Outline of Scheme.

Storage is provided very easily by simple works in Jackson Lake at the main source of the river and over 250 miles above the irrigated area. The diversion weir across the Snake River raises the level by about 42 feet, and canals take off above the weir on both sides. As at least 2000 cusecs must always be passed down the river to the Twin Falls South scheme, which has an older water-right, advantage is taken of the drop at the weir to generate electric power which is used throughout the scheme and especially for pumping to the high lands on the south side.

This high weir causes a lake (called Walcott) which extends thirty-two miles up the river and forms an extensive storage basin, only the upper layers of which, however, are available on account of the height of the canal sills. Both canals begin to irrigate within a couple of miles of the weir. The north canal soon branches out into a number of smaller canals which follow minute elevations in the extraordinarily flat tract where the variation in level does not exceed 20 feet over the whole stretch, which is twenty miles long and has a maximum width of about ten miles. The south-side canal follows for thirteen miles the edge of a bordering steep slope with a narrow stretch of lands between it and the river, which is between one and two miles away, and continues about the same distance from the river for about

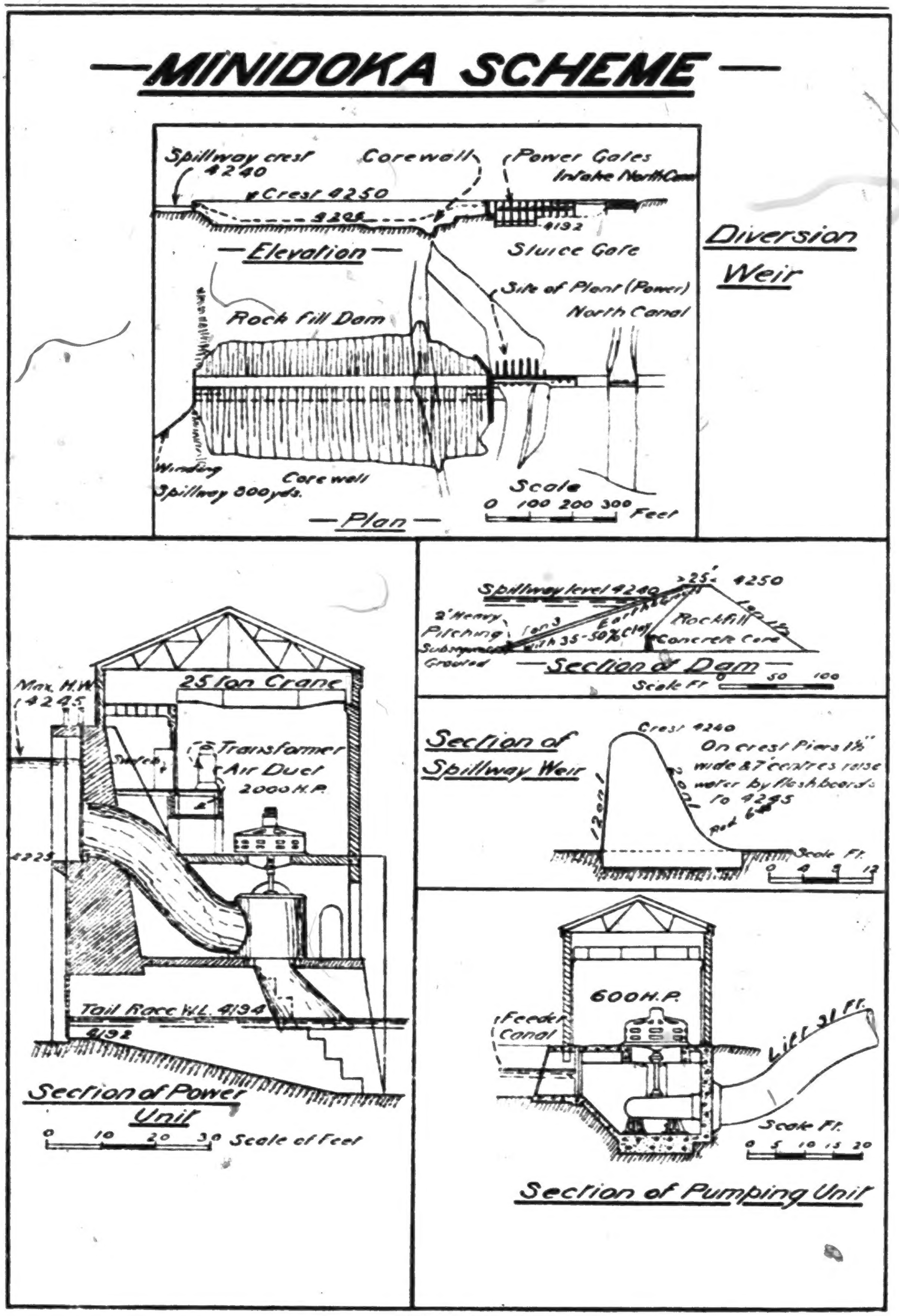

MINIDOKA SCHEME
Spillway crest 4240
Corewall
Power Gates
Intake North Canal
Crest 4250
4205
4192
Elevation
Sluice Gate
Diversion Weir
Site of Plant (Power)
North Canal
Rock fill Dam
Winding Spillway 800 yds.
Core wall
Scale
0 100 200 300 Feet
Plan
Spillway level 4240
25'
4250
2' Heavy Pitching Submerged Grouted
1 on 3
Earth with 35-50% Clay
Rockfill
Concrete Core
1 on 1½
Section of Dam
Scale Ft 0 50 100
Max. H.W. 4245
25 Ton Crane
Switch
Transformer
Air Duct
2000 H.P.
4225
Tail Race W.L. 4194
4192
Section of Power Unit
0 10 20 30 Scale of Feet
Section of Spillway Weir
Crest 4240
On crest Piers 1½" wide & 7' centres raise water by flashboards to 4245
1 on 12
1 on 2
Scale Ft. 0 4 8 12
600 H.P.
Feeder Canal
Lift 31 Ft.
Scale Ft. 0 5 10 15 20
Section of Pumping Unit

Fig. 27.

twelve miles further. At the thirteenth mile, by means of pumps deriving power from the weir, the water is raised in three steps to high-level canals, which run parallel to the gravity canal and the river, irrigate the high lands as far as six miles from the river, and end in a bluff which also terminates the gravity canal.

Works.

Lake Jackson Storage.

A comparatively small work was required here to turn the lake into a storage basin. A dam has been built at the outlet with sluice gates and a spillway 24 feet above the bed of the stream. An area of 22,600 acres is covered with water and a storage of 380,000 acre-feet is available.

The Diversion Weir.

At the site chosen for the weir the channel of the river was about 200 yards wide with solid bed and sides of lava. This has been entirely blocked by a rock-fill dam, 86 feet high in the deepest part (which is a channel about 30 feet wide), and of an average height of about 50 feet.

On the south bank, formerly beyond the reach of floods, the country consisted of lava-rock at a gentle slope towards the river. The overflow-weir has been constructed on this and runs for 800 yards in a snake-like line following the high rock. It is a concrete weir, varying in height from 2 feet to 15 feet, and with crest 10 feet below the rock-fill dam blocking the river The south canal takes out at the end of this with sill 6 feet below the spillway-crest.

On the lava of the right bank, at the north end of the rock-fill dam, is the power-house. Sluices were placed here with sill 58 feet below the rock-fill crest to keep the level of the river down during construction of the dam across the river. Further north are the intake gates to the north canal with sill 10 feet below spillway-crest. The most difficult part of the works was the filling of the original river-channel with the rock-fill dam. As will be seen from the section on fig. 27 and photo C, plate 8, this consists of a rock-fill on the down-stream side, with a concrete core-wall at its up-stream toe and an earth and gravel filling above this with a pitched slope at 1 on 3. The whole structure, including spillway, etc., is about three-quarters of a mile long from end to end and cost about $570,000.

All along the crest of the weir (see photo D, plate 8) concrete piers, 1½ foot wide, have been built at 7-foot centres, and between these flashboards are used up to 5 feet above the crest for regulating the height of water above the dam. This method of regulation has been found to be slow, and, as there is no method of lowering the lake level below the canal beds, except through the old sluices under the power-house, the discharge of which interferes with the draught tubes of the turbines, four new sluices are now being erected in the deep part of the spillway. Each of these will be 10 feet wide by 12 feet deep, with sill 12 feet below the spillway-crest. It is interesting to note that the radial type of gate is being adopted to work under a head of 17 feet. Water-tightness is secured simply by 6-ply rubber strips 7 inches wide attached to the gate-ends, as shown on drawings of these gates on fig. 28.

The power-house contains five main generator units each of 2000 h.p. capacity. The turbines are 54-inch Francis type with a head of 46 feet. The axis is vertical and connected directly with Allis-Chalmers' dynamos generating 2200 volts at 200 r.p.m. Current is sent out at 33,000 volts. The whole cost of the power plant, including building, machinery, and installation, etc., was $433,000.

North Canal.

The head-gates consist of nine cast-iron gates, 5 feet wide by 6 feet high, and the sill is 10 feet below spillway-crest. The lands on the north side are lower than on the south side, and considerable drop is given to the canal in the first two miles through lava-rock. In this part it has a slope of 1 in 2000, bed-width of 30 feet, and full-supply depth of 10 feet. At the end of this length it drops 12 feet and thereafter runs in soil at a slope of 1 in 5000 with a bed-width of 46 feet, side slopes 1 on 3, full-supply depth 7½ feet, and capacity 1400 cusecs. After six miles the lands begin to widen out into the alluvial pocket of 72,000 acres. This is by far the flattest piece of irrigated ground of such size which I saw in America. The fall through the whole area is very slight, barely 1 foot per mile, and roughly parallel to the river. Studying a 10-foot contour map, the 4210-foot contour runs in a wavy line through the upper part of the lands; practically the only other contour on the rest of the area (over three-fourths) is the 4200-foot, which wanders all over the area in an irregular maze with a multitude of islands formed by closed 4200-foot contours.

No other scheme in the neighbourhood or even in America has anything like such a flat surface as this; indeed, it is too flat for proper construction of distributaries and for economical application of water to the land. Unlike other schemes, which usually have a main furrow running round the edge of the land farthest from the river, with distributaries running on ridges towards the river, the main furrow on this flat soon divides into a number of branches which further ramify and struggle on at far too flat a slope, following as far as possible one little knoll (invisible to the eye) after another.

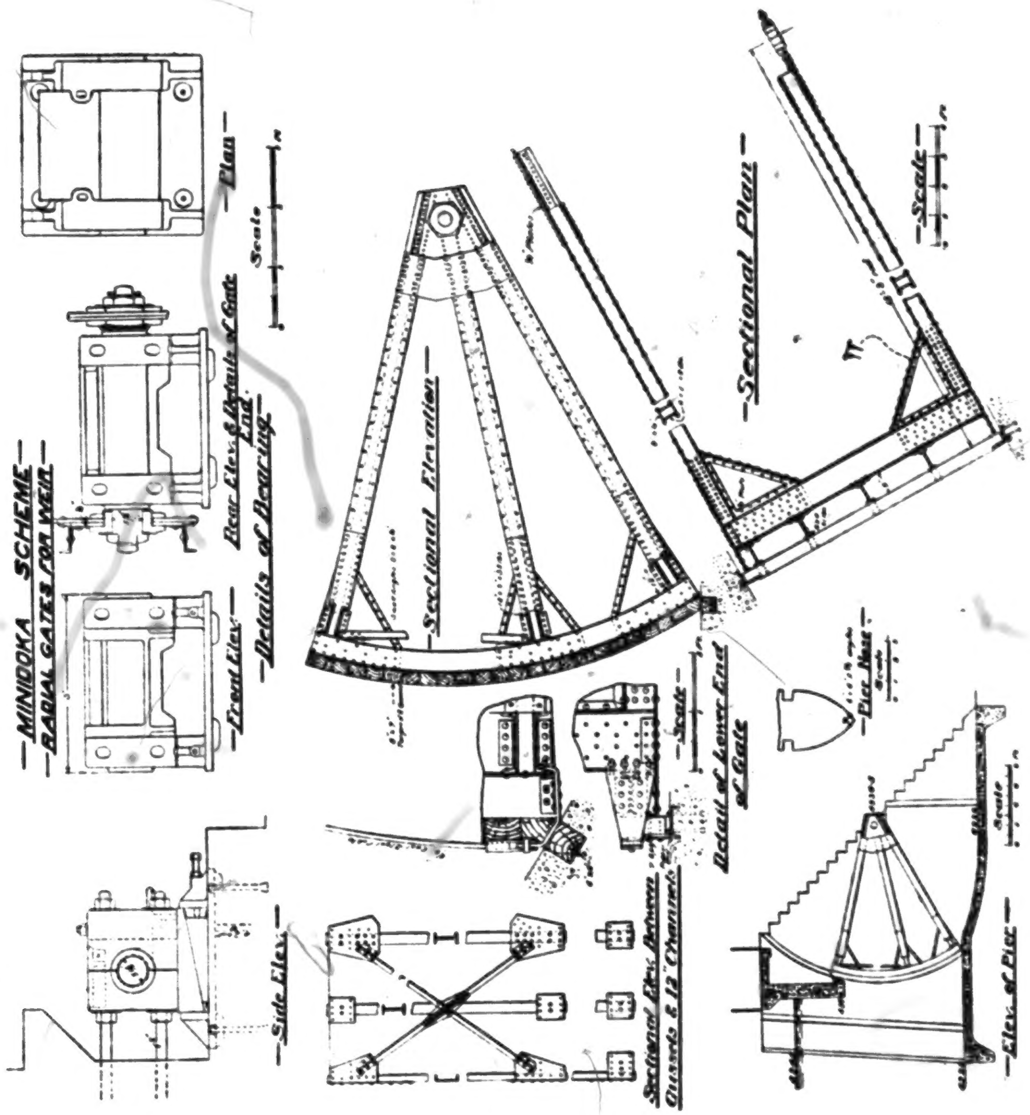

MINIDOKA SCHEME
RADIAL GATES FOR WEIR
Plan
Scale
Rear Elev. & Details of Gate End
Details of Bearing
Front Elev.
Side Elev.
Sectional Elevation
Sectional Plan
Scale
Detail of Lower End of Gate
Scale
Pier Nose
Scale
Sectional Elev. between Gussets & 12" Channels
Elev. of Pier
Scale

Fig. 28.

The slope in the distributaries, big and small, is usually 1 in 5000, and nearly all of them run for most of the way banked up and only slightly excavated, so that the water surface in the canals is generally 2 to 3 feet above the ground. Checks are abundant on all the canals in order to head up the water for minors or farm ditches running to high patches. The disadvantages of such a system of distribution are enormous, not the least being the constant danger of breaching and excessive seepage.

It is remarkable that, while this extraordinary flat stretches along the north bank of the river, immediately opposite on the south side the conditions are entirely different and the slope of the lands is generally between 10 and 20 feet, or steeper, per mile towards the river.

South Canal and Pumps.

The sill of the canal intake on the south is 4 feet higher than that on the north. The canal has a longitudinal fall of 1 in 5000 and a capacity of 800 cusecs. Its alignment is for a great distance in porous lava-rock at a steep slope, and consequently leakage is considerable. It commands only a narrow strip, a couple of miles wide, down to the river. The greater part of the irrigable lands lie too high to be commanded by a gravity furrow, and, consequently, the power generated at the head weir has been utilized to pump water from the south canal to the high lands above it; a total area of 48,000 acres is to be served by the pumps.

The pumps derive their water from the south canal at its thirteenth mile. A small part of the water is delivered to a canal 31 feet above the main canal. A larger part is delivered to a canal at 62 feet, and the remainder at 93 feet. There are three pumping stations. The first station pumps all the water required by the three canals, nearly 675 cusecs, 31 feet high. Of this water, 75 cusecs are used in the lowest canal, and the remaining 600 cusecs are then raised another 31 feet at the second pumping station, 275 cusecs of this being fed into the middle-level canal, and the remaining 325 cusecs raised another 31 feet at the third station and fed to the highest canal. As the country slopes fairly gently and in steps towards the river, the stations are some distance apart, and feeder-canals connect the stations with each other, the canal between the first and second station being 1¾ mile long, and between the second and third station three-quarters of a mile long.

The first station contains four 125-cusec units and one 75-cusec unit. The second station contains four 125-cusec units, and the third station two 125-cusec units and one 75-cusec unit.

Each unit consists of a motor with vertical axis directly connected to a pump below. Each pump is located in a separate chamber below full-supply level in the feeder-canal, and is separated from the latter by a gate. Each pump chamber can therefore be emptied separately. The pump is of the vertical-shaft type with both top and bottom suction. The discharge is controlled by a cylinder-gate between the impeller and diffusion vanes. The impeller is 44 inches in diameter, the discharge pipe is 48 inches diameter, and this enlarges to a reinforced pipe 5 feet 6 inches diameter. Where this discharges into the upper canal, tide-flaps are provided. Current from the transmission line is delivered at 30,000 volts and transformed to 2200 volts in the first and second pumping stations, the latter supplying the third station at 2200 volts. Each large driving motor is 600 h.p., 3-phase synchronous, and operates at 2200 volts and 300 r.p.m. For starting, an auxiliary winding allows it to speed up as an induction motor under 600 volts. Before synchronizing, the fore-bay gates are closed and the pump empties its own pit at a low head. When proper speed is obtained the motor is thrown into the 2200-volt line, the gates are opened, and pumping to full head can begin. The smaller units are similar, but of 360 h.p.

The efficiency of the system, starting from the water power at the diversion-weir, is as folows:—

Power House	Turbines	81·5	per cent.
	Dynamos	78·2	„
	Step-up Transformers	77·0	„
Transmission Line		69·3	„
Pumping Plant	Step-down Transformers	67·9	„
	Motors	63·8	„
	Pumps	46·3	„

The cost of the three plants is as follows:—

	Plant 1.	Plant 2.	Plant 3.	Total.
Excavation	$2,100	$5,300	$2,000	
Building	35,000	40,000	19,500	
Hydraulic machinery	27,200	23,000	16,200	
Electrical machinery	44,700	42,800	17,300	
Freight and hauling	10,300	9,600	5,500	
Erection	15,800	14,600	9,300	
Concrete delivery pipes	21,400	16,500	20,200	
Camp and quarters	4,000	11,000	500	
Engineering and overhead, etc.	13,500	10,000	7,500	
Totals	$174,000	$172,800	$98,000	$444,800

Soils, Slopes, Methods of Irrigating and Drainage.

The soils on the north are generally lighter, more sandy, and looser than those on the south, and the greater portion might be called a light sandy loam. Much of this soil is so light that winds blow it about easily when dry, and for this reason difficulty is experienced in establishing lucerne unless the soil is kept constantly moist. Underlying most of the area at a depth of 2 feet to 4 feet is a sand and gravel bed from 4 feet to 40 feet in thickness. Below the sand and gravel is clay resting on rock. The soils on the south are generally heavier and more compact, and also overlie sand and gravel. As we have seen, the surface of the land on the north side is extremely flat, having a slope of barely one foot per mile parallel to the river, whereas on the south side the slope is 10 to 20 feet or more per mile and square to the river.

Methods of Irrigating.

On the north side, on account of the flatness, the method of irrigating in enclosed basins by basin-soakage is generally practised. There is not sufficient fall to allow streams to be run over slight elevations, and, without very fine levelling, the only way of covering the high parts is to head the water up in basins. The Indian, confronted with similar conditions, would level off each bed with the precision of a tennis lawn and in this way use his water economically, but such precision is not practised here, and water stands several inches deep in the lower parts before the higher parts are flooded. Under these conditions, the basin method is naturally very wasteful, especially when the shallow covering of soil rests on gravel. On the south side the greater slope makes irrigation by surface flow between borders an easy matter.

The water-table has risen to very near the surface over a large area, and in such parts a very bad method of irrigation, locally called "sub-irrigation," is practised. At the beginning of the season water is run through the area to such an extent that the water-table rises sufficiently to keep the surface moist throughout the season without further irrigation. The chief advantage of this method is that in the very sandy soils lucerne does not suffer from strong winds which otherwise give great difficulty. The practice is very general, and thoroughly bad, and areas irrigated in this way often become ruined by seepage.

Drainage.

On account of the high elevation of the distributary canals above the surface, and the wasteful basin and "sub-irrigation" methods of irrigation on the north side, we would expect that the seepage losses would be great, but that the gravel substratum might carry this off without allowing the spring level to rise to a dangerous height. We have learnt, however, from the schemes previously described, especially the Shoshone scheme, that the water-table will rise in spite of such an apparently favourable condition, and this has happened here and expensive drainage has been found necessary.

Although irrigation on this scheme was commenced only in 1907, by 1912 over sixty miles of drains had been constructed. Drainage is not easy on this scheme, where the slope is only 1 foot a mile, and the lands lie only 20 feet above the water surface in the river. On the Shoshone scheme the usual slope was 1 in 200, and on the Huntley scheme about 1 in 700, but here the steepest general surface-slope for drainage is 1 in 5000. Pipe drains would cost much more than open drains, as very large pipes would be required with so little fall. Consequently, open drains have been generally adopted on this scheme.

At first shallow drains with a bottom-width of 3 feet and side slopes of 1 on 2 were dug, but the later drains are mostly 8 to 10 feet deep, with bottom-width up to 10 feet. Observations have been made on the discharge of the drains, and it has been found that during the irrigating season the average inflow per mile of drain was 1 cusec for shallow drains and 2⅓ cusecs for deep drains, and it is estimated that the total discharge of all the drains for a whole year is 40,000 acre-feet, which is over 10 per cent. of the water diverted and about 1 foot depth over the whole area actually irrigated. The cost of drainage works has already exceeded $200,000.

The shallow excavation was done with ordinary scrapers, but, for the deeper trenches, especially where water was abundant, the dragline excavator is now used. Two 50 h.p. engines with 50-foot booms and 1¼ cubic yard buckets are used, and cost $5000 each. They can work ahead of the cut up to 12 feet depth, but for deeper cuts have to work from the sides. They can be worked in water up to 4 feet deep. The average cost of excavation with them was 14 cents per cubic yard.

The annual cost of keeping these drains clean is considerable, as the fine sand and gravel slopes cave in, and weeds, such as Russian thistle and "tumble weed," when dry, blow in in great masses. Where open cuts have failed to relieve the seepage, advantage has been taken of the cheap electric power generated at the weir site to facilitate drainage by means of pumping in a few places. A 20-cusec pump has been sunk alongside one of the open drainage cuts and 12 feet below it. To this a number of drainage lines flow with a better fall than could otherwise be obtained, and the pump lifts the water to the open drain above.

It is fortunate that there is very little alkali in the natural soil, the chief trouble being simply seepage.

Mention should be made of a peculiar method of draining some large shallow lakes in the area farthest away from the river and therefore most difficult to drain by open cuts. Boreholes have been sunk here about 100 feet deep and into the underlying rock. It is found that water drains down these holes and gets away through cracks in the rock. One 6-inch hole carried away as much as 6 cusecs.

Crops. The total area actually irrigated in 1912 was about 70,000 acres. Of this 37,000 were on the north side and 33,000 on the south, of which 30,000 were under the pumping system. The biggest crop is lucerne, which occupies 40 per cent. of the area. Cereals occupy 33 per cent., hay and pasture 10 per cent., potatoes 5 per cent., and sugar beets 4 per cent. Lucerne gives about 3 tons per acre and sells at $5 per ton. Wheat gives about 18 bushels per acre and sells at 66 cents. Potatoes, which occupy as much as 3500 acres, bring in 118 bushels per acre and sell at 25 cents. A sugar beet factory has been erected on the scheme, and no doubt this crop will now increase rapidly as the beet crop has at Huntley. At present the returns are only 7 or 8 tons per acre, valued at $5 per ton.

Settlement and Cost. The scheme is practically completed and can now supply a total area of 111,300 acres. Almost the whole area was Federal land, and there were no complications as at Boise on account of private ownership or old schemes. About 90 per cent. of the area has been settled, and 70 per cent. was actually irrigated in 1912. Only the lands under the gravity system have up to the present had building charges fixed, a water-rent being charged for the lands under the pumping scheme.

The first lands were given out with a building charge of $22 per acre, to be paid in ten equal instalments. Many settlers were unable to meet the first payments, and a graded system of payment was offered on condition that the building charge be raised to $30 per acre, and 70 per cent. of the settlers agreed to this. The few private owners and those who have bought school lands are charged $40 per acre.

For the lands under the pumping system no building charge has yet been fixed, and a simple annual water-rate of $1.10 (in addition to $1.50 for maintenance and operation) is charged per acre to all settlers under the scheme, whether they use the water or not. The supply allowed for this payment must not exceed a total of 1.75 foot per acre during the months of June, July, and August. For all water used in excess of this there is a charge of 20 cents per acre-foot.

The whole building cost to date is about $3,800,000, of which over one-quarter was for the power and pumping stations. The power sold for domestic use also brings in a revenue.

The maintenance and operation charges have been raised from 75 cents to $1.75 per acre. The total actual cost to Government per acre irrigated in 1912 was $3.3, including betterments (chiefly drainage). The cost of drainage work on the north side in 1912 was $3.50 per acre irrigated on that side. The chief maintenance charge in clearing canals is due to growth of moss and to weeds blowing in. The close "frog" moss gives little trouble, but two sorts of long hairy moss grow abundantly in the sluggish canals and have to be removed. A heavy chain drawn by horses on both banks is used effectively for this purpose. There is a peculiar bush-weed, called "tumble-weed," which grows thickly over the whole sowing area. It has a brittle stem when dry, and in autumn the strong winds break it off easily and blow it into canals, where, with Russian thistles, it often blocks up the flow at obstructions.

As irrigation commenced only in 1907, the scheme has settled up very rapidly, and from a settlement point of view is very encouraging. The settlers have formed several co-operative buying and selling associations, have good telephone connection with farms, and have a large number of schools, each with several conveyances which collect and disperse the children daily. They enjoy the advantages of very cheap electric power from the weir, and electric light as well as electric cooking and heating apparatus is to be found in most homesteads. Power for electric lighting is sold at 7 cents per kilowatt-hour. For heating, a 4-kilowatt heater, which suffices for a small room, is supplied at a flat rate of $50 for eight months, and a 7-kilowatt heater, which suffices for a large room, at $80 for eight months.

Distribution of Water and Duty.

For the distribution of water four canal superintendents and twenty-four ditch-riders are employed.

Measurements of water are made with greater accuracy under the pumping scheme (where the water is sold by volume) than in the other parts of the scheme.

Deducting water wasted to the river, the average supply taken from the river amounted to 6¼ feet per acre over the 70,239 acres irrigated in 1912. This figure is high, especially as heavy early spring and mid-summer rains assisted irrigation, and would be higher still but for the economical use under the pumping system. For the gravity system on the north side it was 8½ feet, and for the south side (which also carries the pumped water 13 miles, the losses being included for this length) it was 12½ feet. The water delivered at the pumps would spread only 3¼ feet deep over the area irrigated by them. The greater economy of the pumping system is due partly to the fact that the maximum allowed is limited and also to the more favourable slope. The great loss in the south-side gravity canal is due to the porous nature of the rock through which it passes. On the north side the high figure is due chiefly to the very flat slope, and consequent heavy loss in the canals and fields. The loss per square foot of wetted area in canals varied from 0.20 to 2.06 cubic feet per day on twenty measured sections. Of the average of 6¼ feet diverted, 4 feet were delivered to the heads of minors and less to the fields. Of the 3¼ feet pumped, about ½ foot was wasted to the river, 2¼ feet reached the heads of minors, and the average application at fields was 1⅔ foot.

Rotation is practised only under the pumping scheme.

As the Minidoka scheme is entitled to the storage made available at Jackson Lake, this is sent down the river as required by the scheme. The difficulty of sending down this water is considerable, as the whole distance is over 250 miles and there are more than fifty canals between Jackson Lake and the diversion-weir. Each of these canals, as well as the Twin Falls South scheme below, with its older right, has to take its water as if the storage water were not superimposed on the ordinary flow. This involves most careful gauging and supervision along the whole length of the river, which is done under the direction of the State Engineer of Idaho.

Plate 9.

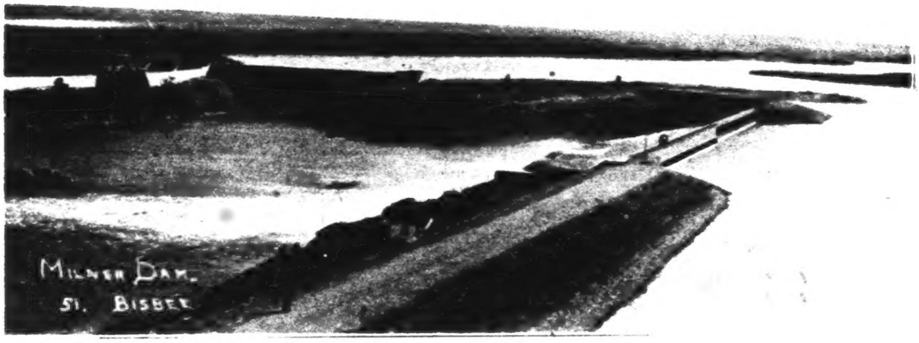
TWIN FALLS SOUTH SCHEME—Milner Weir.

Milner Dam Gates

(*a*) Regulating Gates from end of South Rock-fill Dam.

Plate 9.

TWIN FALLS SOUTH SCHEME—Milner Weir.


MILNER DAM.
51. BISBEE

(b) Weir from left bank, near entrance to South-side Canal. North-side Canal Wall visible across river on left.

CHAPTER VI

THE TWIN FALLS SOUTH SCHEME
AND
THE TWIN FALLS NORTH SCHEME.

THE following four schemes are all Carey Act enterprises. They are (1) Twin Falls South scheme, (2) Twin Falls North scheme, (3) Oakley scheme, and (4) Salmon River scheme.

The Carey Act is explained in Chapter XVII with particular reference to Idaho, which is the leading State in development under the Carey Act. At the end of 1912, under this Act, twenty-six schemes had a total segregated area in Idaho State of nearly 1¼ million acres, of which over one-quarter was actually irrigated in 1912. Twenty-five more schemes were under consideration in 1912, and the lands withdrawn for them amounted to another 1¼ million acres. This great development is due largely to the great success of the Twin Falls South scheme, under which lies more than half the area actually irrigated by Idaho Carey Act schemes in 1912.

THE TWIN FALLS SOUTH SCHEME

Outline of Scheme.

The "Milner" diversion-weir is built at the head of the great canyon of the Snake River. As previously explained, the river here suddenly changes in character. Above the Milner weir it has a moderate fall and low banks. Immediately below the weir it dives swiftly down into a deep and narrow canyon with many waterfalls and a total drop of 1500 feet in 60 miles. The canyon is very narrow and has precipitous sides. Immediately bordering the canyon is a plane, covered with soil and sloping down towards the river from high hills some ten miles distant. This plane, although several hundred feet above the river in the canyon, is yet lower than the river above the Milner weir on account of the great and sudden drops in the river below Milner. The weir at Milner raises the water-level there about 50 feet, and the main canal runs from the weir for about 80 miles to the tributary Salmon River, keping as high as possible to the south and commanding all the land, some 240,000 acres, sloping down from it towards the Snake.

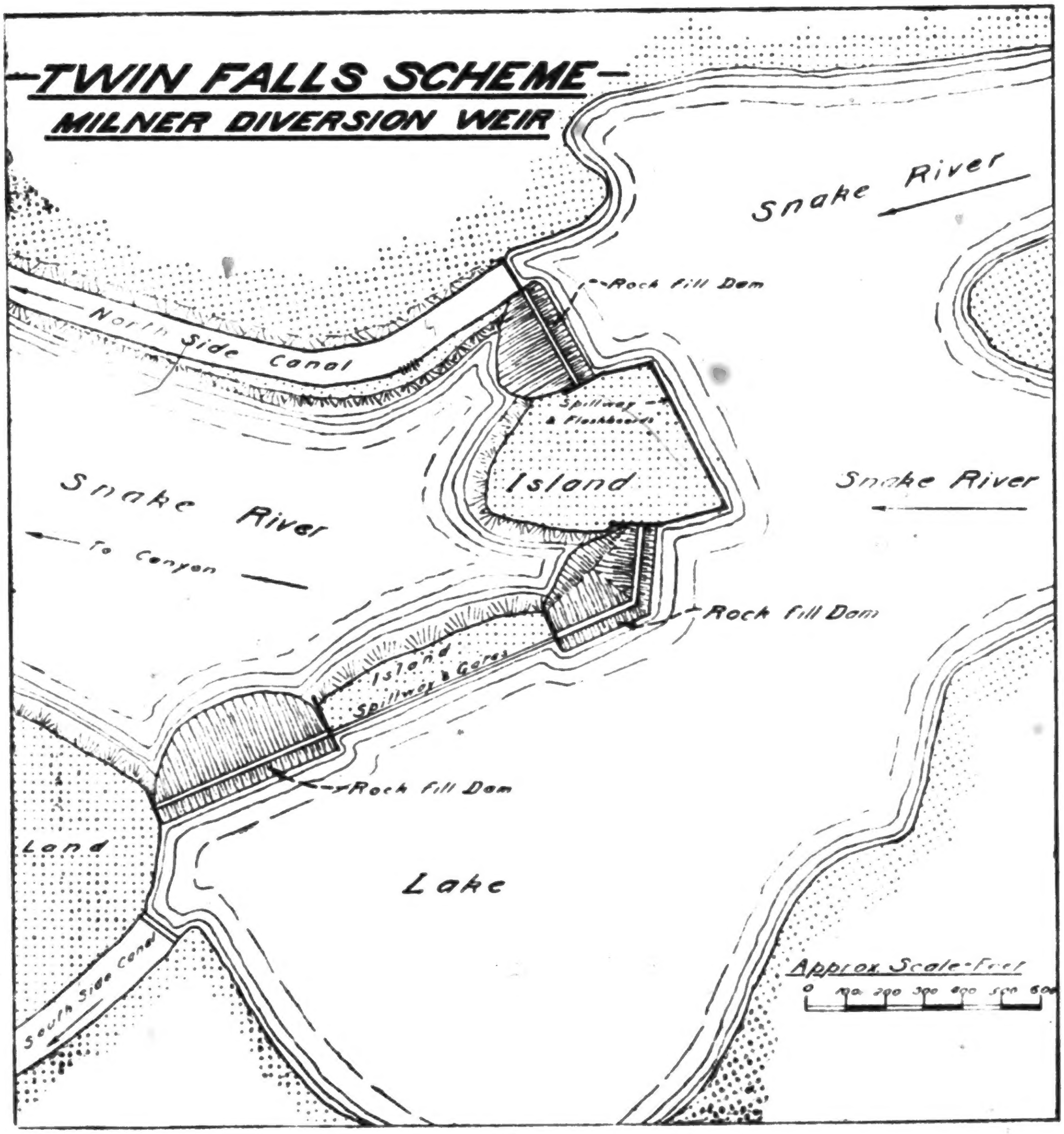

TWIN FALLS SCHEME
MILNER DIVERSION WEIR
Snake River
Rock fill Dam
North Side Canal
Spillway & Flashboards
Island
Snake River
Snake River
To Canyon
Rock fill Dam
Island Spillway & Gates
Rock fill Dam
Land
Lake
South Side Canal
Approx. Scale-Feet
0
100
200
300
400
500
60

Fig. 28.

Milner Weir.

The plan of this weir is shown on fig. 29 (see also photo B, plate 9). In design it roughly resembles the Minidoka weir which was built after it. The river originally flowed in three channels with two islands separating them. The deepest channel was on the north, and this has been blocked with a rock-fill dam 80 feet high, as at Minidoka, but with a much flatter up-stream slope—nearly 1 on 10. It is about 100 yards long on the crest. The other two channels are blocked with similar rock-fill dams, not so high, and with slopes up-stream about 1 on 4, and down-stream 1 on 1½. The middle dam is about 120 yards long, with a bend in the middle, and the south dam about 160 yards long. The two islands have been used as spillways, the one on the south island being straight and the other extended up-stream in the form of a U, the combined length of the two being about a quarter of a mile. The tops of the islands being very level, the spillway-weirs on them are low and simple.

Flashboards are used on the north island, and on the south island about ninety wooden gates 10 feet high by 5½ feet wide do most of the regulating. The crest of this weir and the canal sills are about 16 feet below the top of the rock-fill dams. The regulating gates and structures over the south spillway are the simplest and lightest imaginable (see photo A, plate 9). The gates, although 10 feet high by 5½ feet wide, consist simply of 8 inch × 4 inch timbers held together by four long vertical 3-inch bolts. Attached to the top of each gate is a casting with a horizontal horseshoe-shaped slot, into which can fit a plate attached to the bottom of a vertical screw on a travelling winch which works the gate both up and down The gate moves in guides, each formed by four angle-irons riveted to a 12 inch × ⅜ inch plate. This is supported behind by a light steel framework which, up to the level of the top of the gates, is embedded in a concrete wall only 9 inches thick and extending 10 feet down stream. A hook is provided to hold each gate up when the travelling winch moves to the next gate. There are also six deep gates near the north rock-fill dam across tunnels through the rock. As at Minidoka, these were of use chiefly for diversion of the river during construction of the rock-fill dams.

The whole cost of the diversion works was about one million dollars.

Radial Gates.

The main canal takes off on the south side in shallow excavation in rock. The head gates consist of nine radial gates of 13-foot span and 11-foot height, curved to a radius of 8 feet. They are of much lighter construction than those described on the Minidoka scheme. The sheath is of wood, supported on an iron framework, and consists of 8 inch × 4 inch timbers jointed to each other by a tongue of thin metal, fitting into grooves in the middle of adjoining timbers. Water-tightness on the sides is secured by nailing on a strip of canvas-rubber. The bearing is simple and works on 2½-inch pins built 5 feet above the sill into the down-stream edge of the buttresses and anchored to them by long rods extending up-stream in the concrete. The strain on the masonry near the bearing must be considerable, and several cracks are noticeable.

Canal and Distributaries.

The main canal has a bed-width of 80 feet, side slopes 1 on 2, long. slope 1 in 7000, full-supply depth of 10 feet, and capacity 3000 cusecs. There are no very difficult structures on the main canal, which runs for 80 miles to Salmon River. The distributary system is also very simple. The slope of the ground towards the river is about 100 feet or more per mile, and numerous coulees (or sluits) with rocky beds cut through the irrigable lands towards the river. Advantage is taken of these for distributary purposes. Water is run down them from the main canal, and pick-up weirs take out water from them where required for canals, which on account of the great slope of the country soon command the lands.

Soils, Slopes, Crops, and Methods of Irrigating.

The soil is generally fine and fairly light. It is derived from volcanic ash or lava, and is consequently rich. It is generally fairly shallow, overlying the lava rock, and in much of the area hardpan is found a foot or two below the surface.

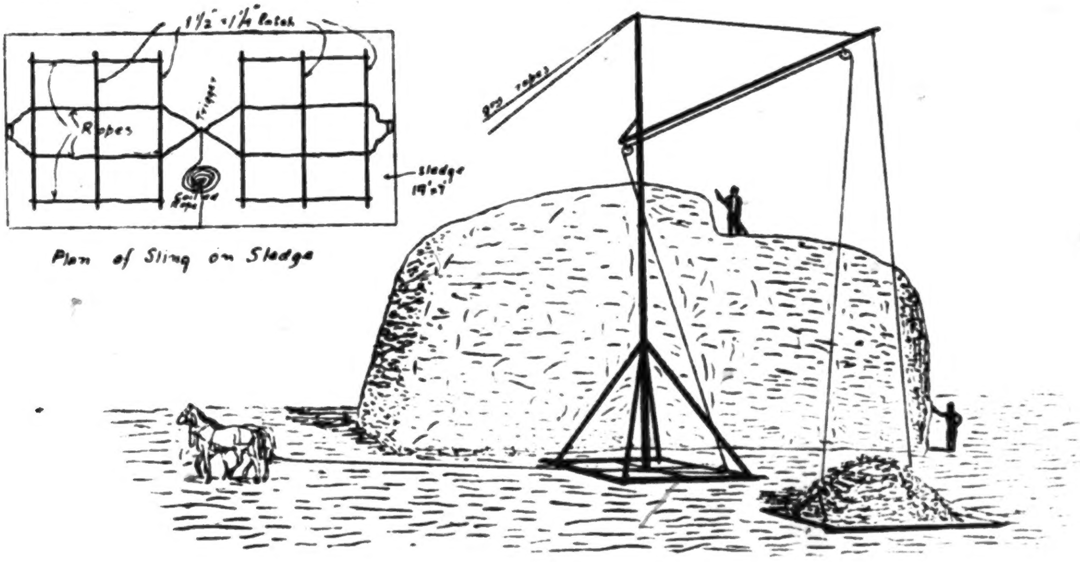
"Corrugation" Irrigation.

The average slope towards the river is 100 feet or more per mile. Probably on account of this great slope and the fine nature of the soil the "corrugation" method of irrigation is very generally practised. Photo A, plate 7, shows the fineness of the soil and the "corrugation" method, which has been described under the Boise scheme.

The soil is in places inclined to cake after surface-wetting, and the corrugation method has this additional advantage that it prevents caking round the actual plant stems. Home-made corrugating implements are used, but for reopening corrugations in old lucerne a sharp instrument is required, and plate 7, B, shows such an instrument, which is known as a "lay-off and pulverizer." The machine illustrated is made by the Utah Implement Vehicle Company of Salt Lake City, Utah, costs $24, and weighs 220 lb. The attachment behind harrows the ground between the furrows, and the rollers leave the furrow in good condition for water. The whole instrument is a very simple and useful one.

Lucerne Crops.

The areas under different crops are roughly in the same proportion as on the Minidoka scheme, lucerne being the chief crop. Three cuttings are usually obtained—the first about the middle of June, the second early in August, and the last towards the end of September. The first crop often does not require water on account of the prevalent spring rains. Waterings are usually given about a fortnight before cutting and immediately after the crop is carted off. Waterings can not be given at a shorter time before cutting, as the heavy crop is liable to blow down. The lucerne is put into shocks a day or less after cutting and remains in them on the field for four to seven days, so that it is usually a week after cutting before the field can be watered again. The first cutting gives a very good hay, the third is softer and more laxative, and therefore not so good for cows as for horses. A simple method of gathering and stacking the hay is worth describing (see fig 30). For carting, a simple wooden sleigh is made of timbers shod with iron. The sleigh is usually 14 feet long and 7 feet wide, and can therefore take a good load, though only two heavy horses are required. Before the hay is placed on the sleigh a slinging



Plan of Sling on Sledge

Hay-Stacking Device Twin Falls

Fig. 30.

Stacking Hay.

contrivance is spread out flat on the bottom so as to lie beneath the hay with ends projecting. It is made in two halves with a detaching joint between them and rings at the outer ends. Each half consists of three 1½ inch × 1½ inch wood laths connected by four ropes. The outer rings and detaching joint are also connected by ropes, and to the trigger of the detaching joint a long rope is fixed and coiled up with end projecting. The elevating gear consists of a mast supported by four props resting on a wooden base which can be moved about on rollers to different stacks. An arm is supported at its upper end by a long rope from the top of the mast, and by a short rope at its lower end from a point lower down on the mast, the arm simply rubbing against the mast where it touches it. The hauling rope has a harness attachment for horses. It passes through three pulleys, one at the corner of the base and one at each end of the arm. It then passes down through two loose pulleys and up to the far end of the arm, where it is fixed.

The loaded sleigh draws up under the two loose pulleys. These pulleys carry hooks which fix into the two rings of the sling, the portion of the pulley rope between them being spread over the top of the hay. The horses which pulled the sleigh are harnessed to the end of the pulling rope, and when they move away, the pulling rope first tightens up the hay in a bundle and then raises it. When the top of the stack is reached, the arm, being on one side of the pole, swings round over the stack. The rope attached to the detaching trigger (now hanging down) is pulled and the two halves of the sling separate, allowing the hay to fall on the stack. When the horses are released the arm swings back and the weight of the loose pulleys and sling bring the latter to the ground again.

Apples are grown fairly extensively, "Jonathan" and "Rome Beauty" being the chief varieties. Quite a number of peach orchards also do very well in spite of the high latitude and altitude.

Settlement and Cost.

The scheme was initiated in 1902. In 1903 a company of capitalists made a contract with Idaho State under the Carey Act to irrigate an area of 240,000 acres on the South side. Eearly in 1903 construction was commenced on the diversion-weir, which took two years to complete; 50,000 acres were ready for irrigation in 1905; the system was completed in 1907, and within a couple of years practically the whole area of over 200,000 acres was taken up by settlers. The contract with the State provided that a charge of $25 per acre for water-rights be made by the constructing company to the settlers, who obtained the land for nominal payment from the State, which in turn got it from the Federal Government. The terms of payment to the company of the $25 per acre were $3 cash on entry, and the rest in nine annual instalments with interest at 6 per cent. In addition the settler has to pay 50 cents per acre to the State, half on entry and the other half within three years. Not more than 160 acres can be entered by one person, and within two years he must have cultivated one-eighth of the area as a condition of obtaining title to the land from the State. He obtains title to the water-right when he has paid the company in full. The original constructing company retains a first mortgage on all holdings until final payments are made.

According to the State law the management of the scheme is handed over by the company to the settlers themselves as soon as 35 per cent. of the sum due to the company has been paid. This condition was soon fulfilled, and in 1910 the settlers formed a company which took over from the constructing and financing company. The present company started with a capital stock of $240,000, or $1 for each acre in the scheme, which entitles each holder to one vote per acre held. A board of five directors is elected annually. They carry on all the business. At the beginning of each year an estimate of maintenance and operation charges is made, and this is payable by settlers in advance. For the last three years it has been 60 cents per acre.

The original estimate for the scheme was 1½ million dollars, and the actual cost to the constructing company was over 3½ million dollars, so that their profits were not so large as anticipated.

The acreage now settled is roughly 214,000 acres, of which about 160,000 were actually irrigated in 1912. This is the biggest area irrigated by any one scheme in Idaho, and the scheme has proved one of the most successful in America.

A railway runs through the area. Cheap power is obtained from the Snake River Falls; and indeed the transformation of this country within the short period of ten years is almost incredible. The scheme is in every way a most successful one.

The first cost to the settlers was low—only $25½ per acre. No storage is necessary on account of the early water appropriation, which assures them of just sufficient water by natural flow every year. In addition, on account of the steep slope, the numerous sluits, and the high elevation above the river, drainage works are not likely to be necessary.

TWIN FALLS NORTH-SIDE SCHEME.

This scheme is verv similar to the South-side scheme. It takes its water from the same diversion-weir at Milner, and with a main canal nearly 100 miles long irrigates a similar tract of country sloping down to the Snake River canyon from the north. The work was commenced only in 1907, and the water appropriation therefore dates after both the Twin Falls South scheme and the Minidoka scheme, which, with other earlier appropriations, absorb the whole of the late summer flow of the Snake above the Milner weir. The whole area embraced in this scheme is about the same as on the South side—240,000 acres.

Works. The canal head gates are similar to those on the South side, and consists of five radial gates of 13 feet span and 10 feet height. The sill is at the same level as on the South side, but the canal bed immediately below is 1 foot 9 inches higher.

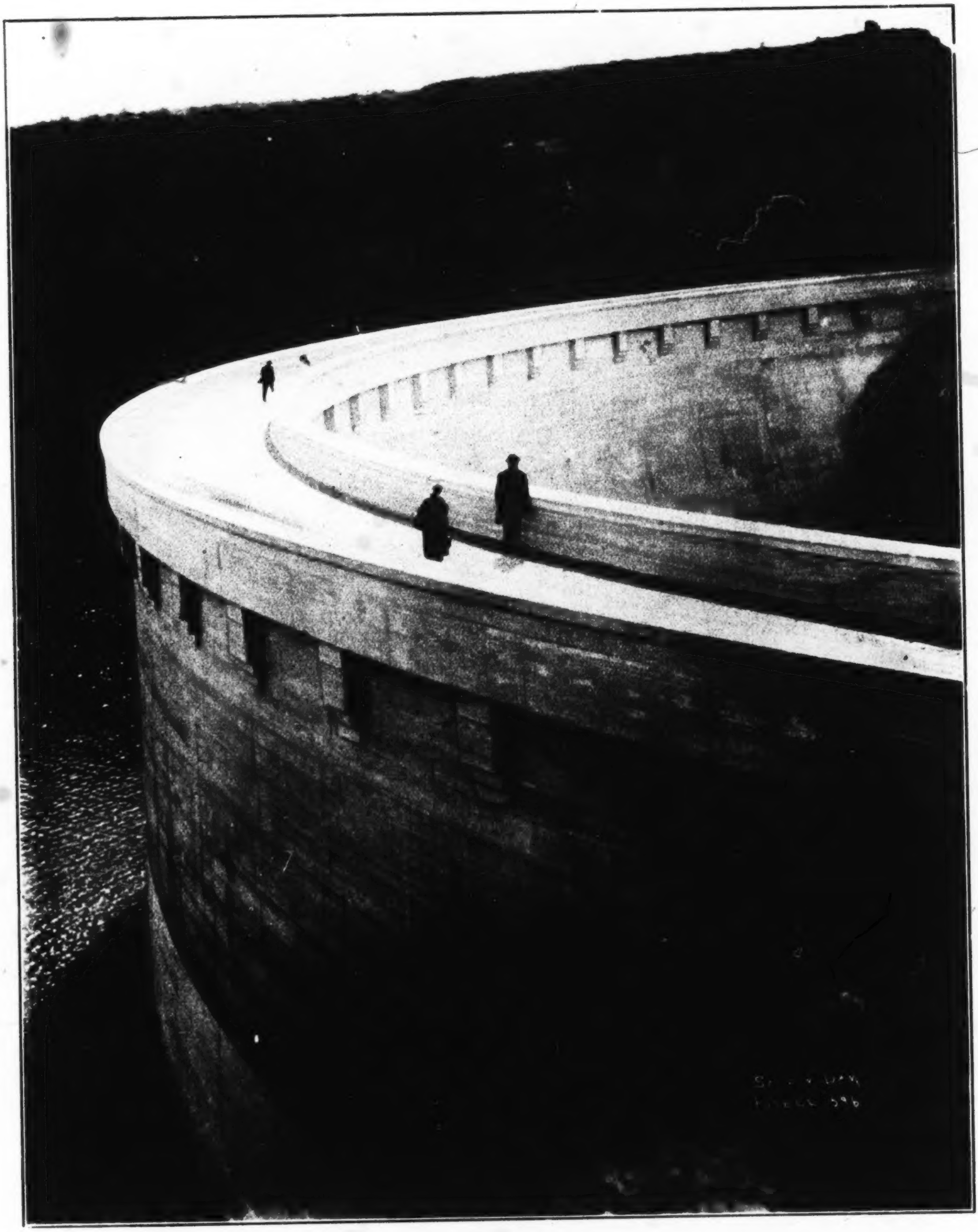
A short distance down the canal five similar but stronger radial gates act as an escape to the river.

The first 8400 feet of the canal pass through very difficult country, and the whole of this length is concrete-lined. From distance 0 feet to 1000 feet the canal is on the side of a steep cliff. The upper half of the section was excavated, the lower half was filled, and a high concrete retaining wall was built on the river side. The bed-width in this length is 61 feet, and the bottom and upper sides are lined with 4-inch concrete. The slope is .0003, full-supply depth 7.75 feet, and capacity 3150 cusecs, though the maximum yet run is 2850 cusecs.

From distance of 1000 feet to 4100 feet the side slope of the country is not quite so steep, and the excavation from the top side forms the lower retaining bank with a slope of 1 on 2. In hollow places the bank is built on both sides. From distance of 4100 feet to 7700 feet the canal passes through a deep rock-cutting, as deep as 25 feet in places. The rock is porous lava, and is therefore lined with concrete. The slope in this length is 1 in 1000, and the bottom-width is 40 feet. The canal is concrete-lined to 8400 feet (where a drop of 4 feet is given), and continues in earth at a slope of about 1 in 5000. At about the seventh mile the main canal passes into Wilson Lake reservoir. Low earth and masonry dams give a storage of 20,000 acre-

Plate 10.

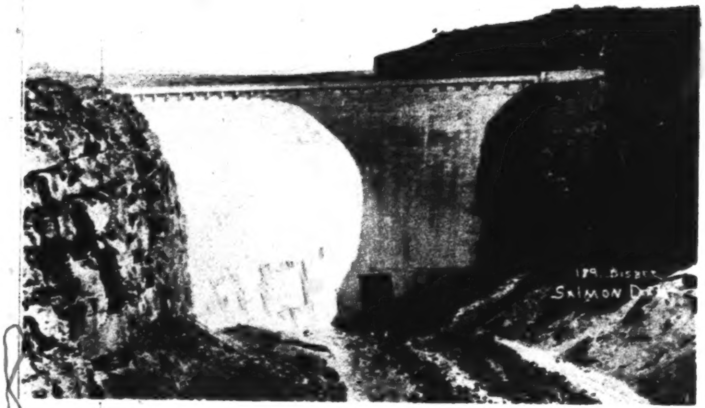
SALMON RIVER SCHEME.



(*a*) Dam from right bank.

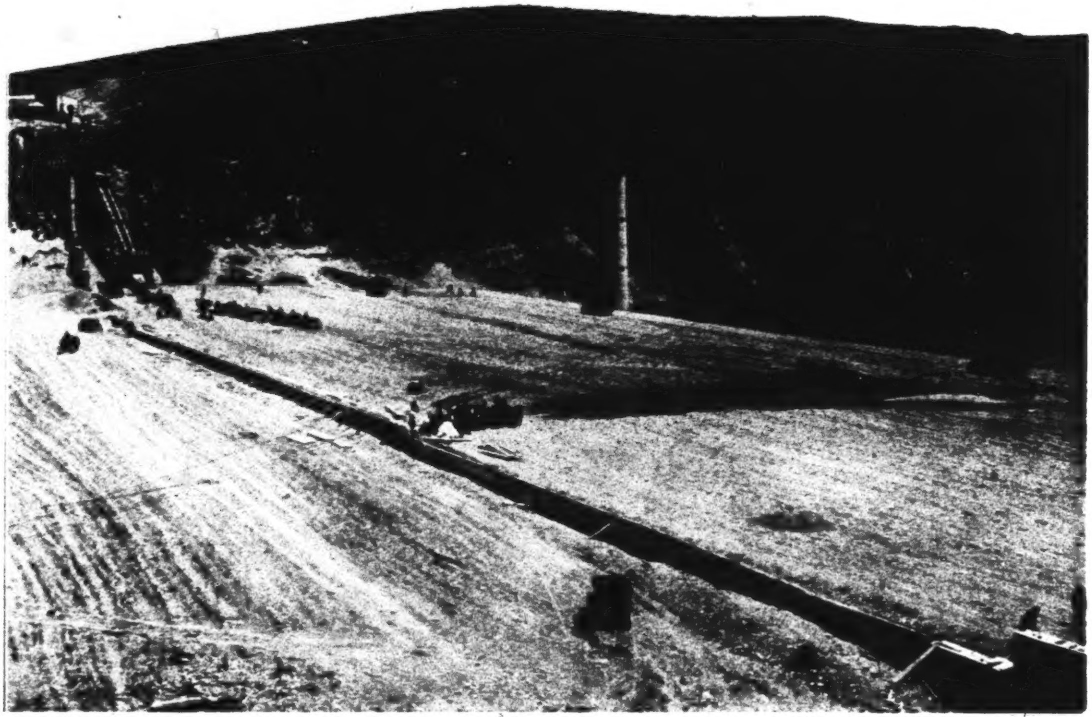
Plate 10.

SALMON RIVER SCHEME.


179. Bisbee
Salmon D

(*b*) Dam from down-stream.

OAKLEY SCHEME.



(*c*) Dam in course of construction.

feet, but the reservoir does not hold water well on account of the porous underlying lava rock. The canal continues—at a level 30 feet lower—from Wilson Lake to Jerome Lake, about 18 miles further. This reservoir is formed by two earthen dams 38 feet and 30 feet high. The capacity is 150,000 acre-feet, but this reservoir also holds its water badly. The canal continues 33 feet lower.

Settlement and Cost.

The first area of 30,000 acres was irrigated in 1908, and by 1911 most of the scheme was completed. Of the whole 240,000 acres, about 170,000 acres have now been taken up by settlers, but the actual area irrigated in 1912 was only 41,000 acres.

The cost to the settlers is $30, $35, and $45 per acre for the sections in the order in which they were thrown open, the largest area being at $35—$3 to be paid in cash on entry and the rest in nine graded annual instalments at 6 per cent. interest. In addition, 50 cents per acre must be paid to the State. The constructing company is still running the scheme, which has not yet been handed over to the settlers. The maintenance charge is limited by the State to a maximum of 35 cents per acre. The actual cost to the company is more. This scheme has not had quite such a happy history as the South-side scheme, chiefly on account of greater cost and insufficient water supply. Several expensive law-suits have been brought by settlers against the company for failure to supply sufficient water. The Minidoka and Twin Falls South schemes, with their earlier water-rights, totalling over 5000 cusecs, absorb all the late summer water, and the two storage reservoirs in this scheme do not hold water well enough. To provide for the periods of shortage the constructing company has had to enter into a contract with the Minidoka scheme to purchase 150,000 acre-feet of stored water from Jackson Lake. The price paid is 15 cents per acre-foot, measured at Jackson Lake, or 22½ cents measured at Minidoka weir, and the whole amount for 150,000 acre-feet has to be paid whether the full quantity is used or not.

The great Kuhn banking-house of Chicago, which, I believe, failed in 1913, financed this scheme, as well as the Salmon River and Oakley schemes to be described later. The scheme has cost over four million dollars. I have not the actual figures of cost, but have heard that the scheme has not been a financial success from the promoters' point of view.

The agricultural and soil conditions are very similar to those on the South side.

CHAPTER VII

THE OAKLEY SCHEME
AND
THE SALMON RIVER SCHEME

THE OAKLEY SCHEME

LIKE the last, this is a Carey Act scheme, promoted by the Kuhn banking firm of Chicago. It provides for the irrigation of 46,000 acres lying south of the Minidoka and Twin Falls schemes. It depends chiefly on storage. The most interesting feature is the dam, an earthen structure 145 feet high, one of the highest in the world. The dam is constructed across the Goose Creek, which is a small tributary of the Snake River. The storage capacity of the dam is 74,000 acre-feet, which is in excess of the whole annual flow during the last three years. Two other creeks—the Birch and the Big Cottonwood Creeks—have therefore been tapped by furrows to augment the Goose Creek supply. The drainage area is 870 square miles. The following are the approximate annual run-offs from Goose Creek for three years:—

Water Supply.

1910	58,000 acre-feet.
1911	50,000 ,,
1912	72,000 ,,
Average ...	60,000 ,,

which is much smaller than for any river previously described.

The following were the monthly means for 1910:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Cusecs ...	84	64	238	209	136	48	27	22	25	31	38	35

Total, 58,000 acre-feet. Mean flow for year, 80 cusecs. The maximum and minimum flows at any time in the three years were 880 and 20 cusecs.

Although 8000 acres in private ownership had acquired previous appropriations, most of the owners sold their rights to the promoters and joined in the scheme, so that practically the whole flow is now appropriated for this scheme.

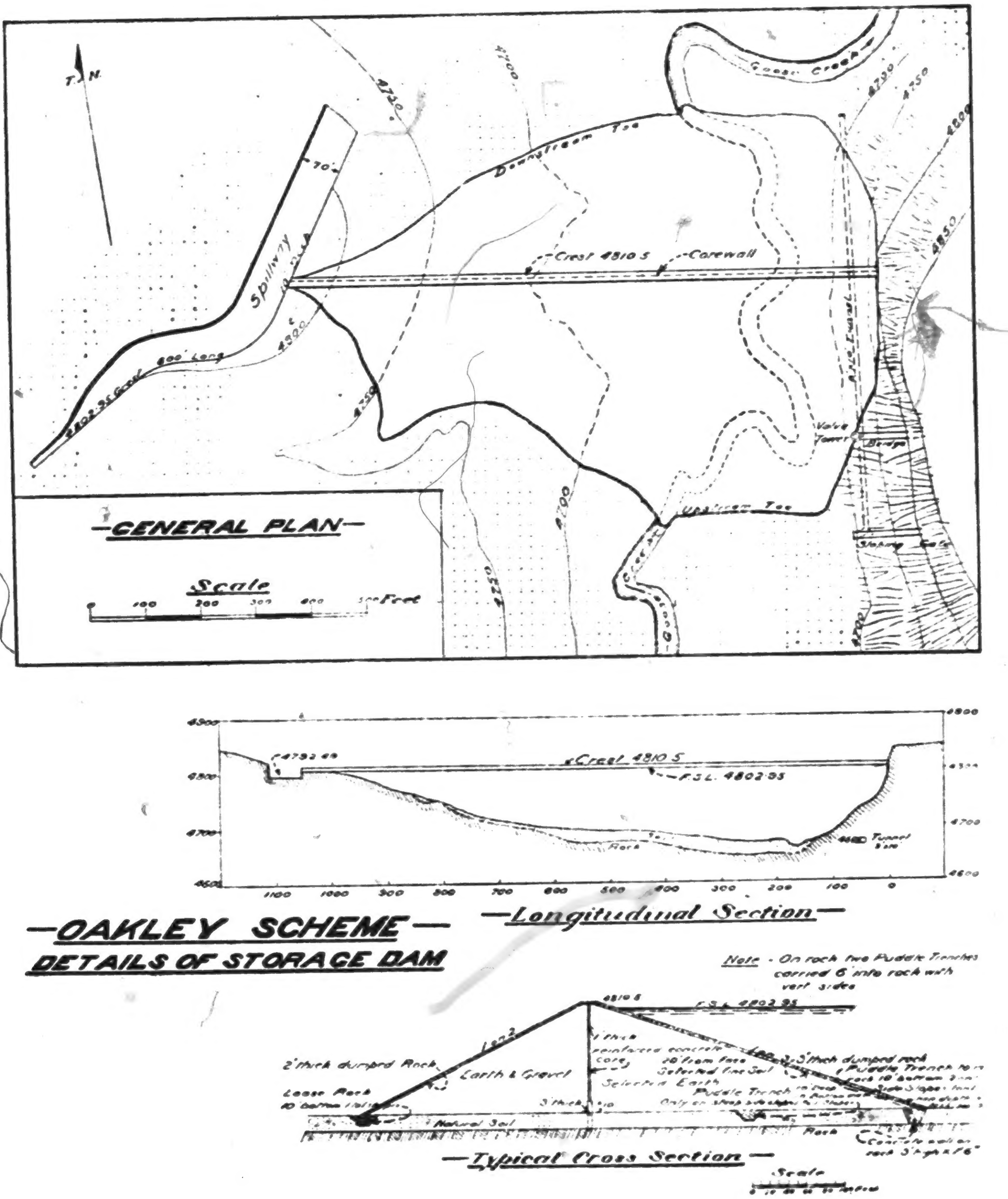

T. N.
Goose Creek
Downstream Toe
Upstream Toe
Spillway
70'
800' Long
4802·95 Grad.
Crest 4810 S
Corewall
Valve Tower
Bridge
Sluicing Gate
4700
4730
4750
4800
4850
GENERAL PLAN
Scale
0
100
200
300
400
500 Feet
4900
4800
4700
4600
Crest 4810 S
F.S.L. 4802.95
Rock
Tunnel Sole
1100
1000
900
800
700
600
500
400
300
200
100
0
Longitudinal Section
OAKLEY SCHEME
DETAILS OF STORAGE DAM
Note - On rock two Puddle Trenches carried 6' into rock with vert. sides
4810 S
F.S.L. 4802.95
1 on 2
2' thick dumped Rock
Earth & Gravel
Loose Rock
Natural Soil
1' thick reinforced concrete core
20' from face Selected fine Soil
Selected Earth
Puddle Trench
3' thick dumped rock
Puddle Trench to rock 10' bottom
Only on steep side slopes
3' thick
Rock
Concrete wall on rock 3' high x 1'6"
Typical Cross Section
Scale

Fig. 31.

From the run-off figures it will be seen that, when water is being drawn for irrigation, it is unlikely that Goose Creek alone will fill the dam. Two furrows, each ten miles long, and of 100-cusec capacity, tap the Birch and Cottonwood Creeks, which run parallel to and on each side of the Goose Creek. They are both much smaller than Goose Creek. The Birch Creek in 1912 had a mean monthly flow of from 0 to 30 cusecs, and an actual maximum flow of 55 cusecs. The Big Cottonwood Creek has, for the last three years, had a mean monthly flow varying from $\frac{1}{4}$ to 74 cusecs and an actual maximum flow of 125 cusecs. There are also prior appropriations on both these creeks, absorbing 16 cusecs in the one and 36 in the other. The storage capacity of the dam is therefore well above the available supply, and the dam is likely to be filled only in exceptional years.

The Storage Dam.

Design.

Fig. 31, page 107, shows the leading features of the dam. The maximum height in the creek bed is 145 feet, and the core-wall here was carried down another 40 feet to rock; the maximum width on the base is nearly 250 yards, and the cubic contents are 1 million cubic yards.

The pitching is of loose rock, 2 feet thick on the down-stream face and 3 feet on the up-stream face, and 65,000 cubic yards of rock were used in the pitching.

The most interesting feature is the concrete core-wall, which is only 1 foot thick in the upper part, and 3 feet thick from bed-rock to 10 feet above natural surface. 6200 cubic yards of concrete were required for this.

The core-wall was reinforced with the American Wire Company's No. 9 mesh reinforcing wire, butt-jointed, and wired together. The wall was built up, together with the earth, in 34-inch lifts, this being the width of the woven reinforcing material. Three other cut-off concrete walls were built on the east side, which was a vertical cliff of fissured lava rock. Eighteen feet of the cliff were first blasted away and the three walls, 18 inches thick, 4 feet deep, and 15 feet apart, were then built into the cliff, up-stream of the central core-wall, being anchored into the cliff by $\frac{7}{8}$-inch square twisted Ransome bars at 3-foot centres. In addition to these walls, two puddle cut-off walls were provided, as shown on the cross-section. Both were designed to be only 10 feet deep, but during excavation the amount of sand and water encountered was so great that it was decided to carry the uppermost puddle-wall to bed-rock, and a concrete wall, 18 inches wide and 3 feet high, was built on the rock in the centre of the puddle-trench.

Earthwork.

Suitable soil for the dam was not found close to the site, so that the borrow-pits had to be located one mile away on the east bank and at too low an elevation to allow a rail-line to be run on to the dam. Consequently, the excavated material was run in trucks for about half a mile, and, for the rest of the distance, was conveyed on moving belts to the dam. The belts are of 6-ply rubber, 36 inches wide, and work in three lengths totalling 1850 feet. They run at 450 feet per minute and require a total horse-power of 145 to drive them. One belt has an up-grade of 16 per cent. Two No. 60 Marion steam shovels excavate the material in the borrow-pits and load into trucks which are drawn half a mile and then dump into a feed-hopper of 300 cubic yards capacity. A small endless belt works under the bottom hole of this hopper and feeds on to the first conveyor-belt. At the end of the belt-line, and on the cliff over the east end of the dam (see photo C, plate 10), the material is delivered into a storage bin of 200 cubic yards capacity. From this bin two shoots (20 inches by 22 inches) at a slope of 47½ degrees deliver into hoppers of 12 cubic yards capacity. The dump wagons, each of 1½ cubic yard capacity, come under these, get their load, and place it on the dam. Sixteen wagons are used, each drawn by two horses.

By means of the above system an average of 95,000 cubic yards was placed per month, and a maximum of 105,000, two shifts working per day. Ploughs and tongued scrapers spread the dumped material in 6-inch layers. The layers have a slope of 1 in 60 away from the east cliff so as to help full-loaded wagons. The layers are sprinkled by nozzle and hose from 2-inch stand-pipes every 100 feet, fed by a 3-inch 2-stage pump in the river bed pumping 100 gallons per minute and driven by a 25-kw. motor. Two 16-ton Avery traction engines compact the material.

Outlets.

The outlet from the dam is through an 8-foot by 10-foot tunnel driven 870 feet through the rock of the east cliff. There are two gate-controls. One, at the upper end of the tunnel, consisting of two 10-foot by 2½-foot gates worked from the cliff at an angle of 45 degrees. The other set is in a reinforced concrete tower. In the latter, there are three sets of ports at levels of 30 feet apart, so that none of them need work at a greater head than 40 feet. The water drops to the bottom of the tower on to a 20-foot water cushion. The design of the gates is very ingenious, and they might be called balanced ring-gates, friction being eliminated by placing the two portals (2 feet by 2½ feet) at each level opposite each other. A ring-casting is built inside the tower with holes at the two opposite portals. Inside this ring-casting is another ring without any holes in the side and with vertical axis concentric with the tower. As the inner ring moves up and down, the portals in the outer ring are opened or closed as required. The pressure from the opposite portals is thus automatically balanced, friction being eliminated, and, in addition, the two issuing streams collide and neutralize each other in the middle instead of impinging on the sides of the tower.

The spillway is similar to the Arrowrock spillway, and required 25,000 cubic yards of excavation in rock, which was used in the pitching.

The whole dam cost a little over 1 million dollars, and the outlet tower $17,000.

Distributaries, etc.

The chief leading furrow is on the west, and is in easy soil-excavation. Its capacity is 320 cusecs. Its bottom-width is 24 feet, and very flat side-slopes of 1 on 3 have been given. On the east the main canal is of 160 cusecs capacity, and there is a small high-line canal of 13 cusecs capacity. Although water had run in these canals for only a year, there was a big growth of long hairy moss on the bottom.

The soil on this scheme is very good and deep, and has an average slope of about 15 feet per mile. Consequently, surface flow between borders is the common method of irrigating, though the corrugation method is also practised over a considerable area. The whole irrigable area below the dam is considerably greater than 46,000 acres, but the State has limited the area to this amount on account of the water supply which will barely suffice even for this limited area. The State has the right to limit the area to be sold under Carey Act schemes, and in this way can protect the settlers against a company which might wish to sell water-rights for a greater area than can be properly served by the works.

Settlement.

Of the 46,000 acres, 8000 were in private ownership of about 200 persons, and were partly irrigated by simple gravity furrows before the scheme was started. All but 3 of the 200 have sold their water-rights to the company, and they now fall in with the general scheme. Work was begun on the scheme in 1910 and practically completed in 1913, the whole cost being about 1¾ million dollars. The greater part of the 38,000 Carey Act lands are sold, the price being $65 per acre paid to the constructing company, and 50 cents to the State. $3 of the $65 are payable on entry, and the balance in eleven graded annual instalments with 6 per cent. interest. 14,000 acres were irrigated in 1913, the first season, and the area is being rapidly increased, homesteads springing up rapidly over the whole area.

It is too early to give maintenance costs and duty figures. The application measured at the fields is limited to 1½ foot per acre, and in 1913 only one-third of the irrigators used more than this.

THE SALMON RIVER SCHEME

The general outline of this scheme is very similar to that of the Oakley scheme, and it will therefore be described only briefly. It is also a Carey Act scheme and, like the last two schemes, was promoted by the Kuhn bank. It is on the Salmon River, a tributary entering the Snake River from the south below the Twin Falls scheme. Like the Oakley scheme, it depends on the storage of the whole flow from a small catchment area, and the chief feature is a high concrete storage dam.

The average run-off of the river at the dam-site for five years was about 126,000 acre-feet, the maximum about 160,000 and the minimum about 90,000.

The mean monthly discharge for 1911 was:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.
Cusecs ...	103	153	319	240	294	270	55	22	26	50	56	49

Total 98,000 acre-feet for the year. Mean discharge for year 136 cusecs. The maximum actual discharge was 953 cusecs in 1911, and in the last five years 2640 cusecs, and the minimum discharge was 18 cusecs.

The useful storage capacity of the reservoir is 180,000 acre-feet, so that it is not likely to be filled and no great spillway provision is necessary.

The details of the dam are shown on fig. 32 and plate 10, photos A and B. Its maximum height is 220 feet. The width of the canyon at crest-level is only 400 feet, and consequently an arched dam has been constructed. The radius is 225 feet, and the subtended angle is 119 degrees. The up-stream face has a slope of 20 on 1 and the down-stream face 2 on 1, giving a maximum bottom-width of 119 feet.

The surrounding rock is lava, which is liable to leak, and probably for this reason, and also because of the limited water supply—although the promoting company applied for 128,000 acres—the State has allowed only about 72,000 acres to be sold. The cost to the settler is $40, plus 50 cents for the State.

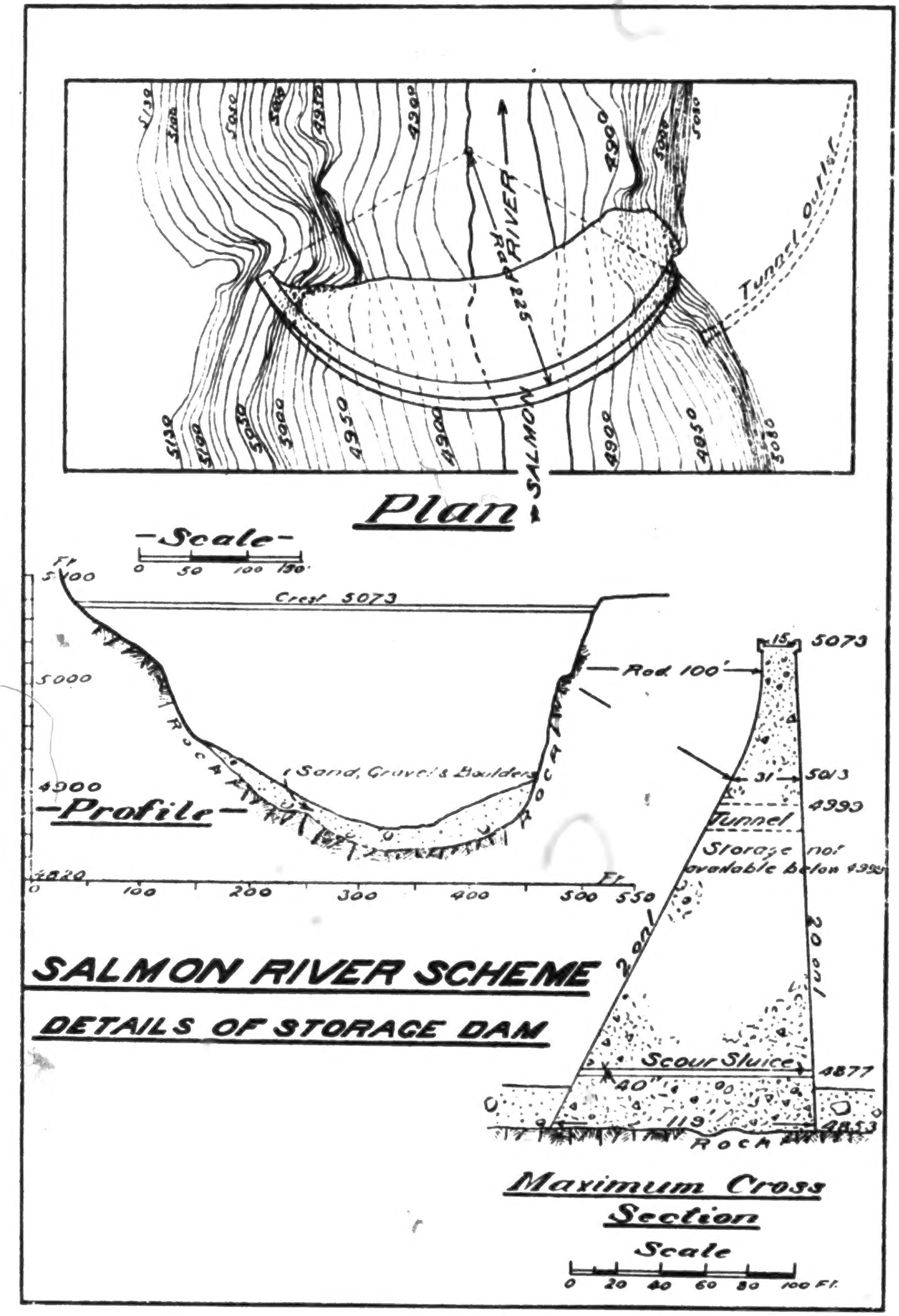

5130
5100
5050
5000
4950
4900
RIVER
Rad. 225
4900
5000
5080
Tunnel Outlet
SALMON
4950
Plan
-Scale-
0
50
100
150'
Ft
5100
Crest 5073
5000
Rod. 100'
Rock
Sand, Gravel & Boulders
Rock
4900
-Profile-
4820
0
100
200
300
400
500
550
Ft
15
5073
31'
5013
4993
Tunnel
Storage not available below 4993
2 on 1
20 on 1
SALMON RIVER SCHEME
DETAILS OF STORAGE DAM
Scour Sluice
4877
40"
119
4853
Rock
Maximum Cross Section
Scale
0
20
40
60
80
100 Ft.

Fig. 32.

Applications for holdings were invited before a fixed day, on which the 72,000 acres were disposed of by lot. The whole area was sold in this way in three days.

The scheme was completed in 1910, and in 1912 only 19,000 acres were actually irrigated. The total cost was about two and a half million dollars.

CHAPTER VIII

CROP EXPERIMENTS AT LOGAN

Utah

On my way south from Idaho I inspected the excellent experiment station at Logan, in Utah, as I was advised that I would probably find the conditions somewhat similar to those in South Africa. I found that the conditions did resemble those in the western coastal parts of South Africa, the chief features being a winter rainfall and a fine sandy soil. The results, however, will not apply to the greater part of central South Africa, where the rainfall is in summer and generally less than at Logan, the soil usually more clayey, and the mean temperature higher than at Logan. The results, which are extremely interesting, will apply to parts of the Western Province, while many of them are of a general nature.

Logan is situated in a valley immediately under the high foothills of the Rocky Mountains, and close to the Great Salt Lake of Utah.

The mean monthly temperature and rainfall are as follows:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Temp., F. ...	24·1	26·2	35·2	47·4	54·3	62·7	71·4	70·6	61·4	47·7	37·8	25·9
Rainfall, in. ...	1·44	1·30	2·00	1·73	2·44	0·86	0·42	0·80	1·07	1·26	1·14	1·02

Total rainfall, in. ... ... 15·48

It will be seen that the rainfall is usually abundant in the early spring, and consequently irrigation is not necessary before ploughing and sowing. This fact makes the results of the experiments of less value for general application.

Over the area where the experiments were carried out the soil is very deep and of very uniform composition throughout. Wells sunk 60 feet did not reach water and the soil to this depth showed no marked variation. Both chemically and physically the soil is extraordinarily good.

The following is the average physical analysis of the upper 8 feet:—

	Coarse Sand.	Medium Sand.	Fine Sand.	Coarse Silt.	Medium Silt.	Fine Silt.	Clay.	Moist.	Soluble and lost.
Per cent.	0·4	8·6	33·2	31·2	10·7	5·9	7·6	1·2	1·2

Broadly this becomes:—

Sand and Coarse Silt.	Silt.	Clay.
72·4	16·6	7·6

This is a good loamy sand.

Generally, South African soils contain a much higher percentage of clay. Dr. Juritz gives a physical analysis of the top foot of a soil on the Smartt Syndicate farms in the Karroo, where lucerne was growing well:—

Sand.	Silt.	Clay.
72·7	13·2	11·3

The soil below this top foot, however, had nearly twice as much clay, and samples from other parts of the farm, where lucerne failed, contained three or four times as much clay. The Logan soil is therefore a more open soil than our Karroo soils. Chemically it is rich in plant food, especially calcium and magnesium carbonates. The favourable physical and chemical analyses are supported by the very high yields obtained (see fig. 33).

The size of plots experimented on was 29 feet × 57 feet, or a little less than one-twenty-sixth of an acre, and a bare space of 7 feet was left between plots. The surface of each plot was made as nearly level as possible, and the stream applied was usually a little less than ½ cusec. The water is clear.

The results for wheat, mealies, and lucerne, given on fig. 33, cover a period of about eight years, and are based on over 250 trials, so that they give a very valuable average.

It will be noticed that the soil-water used is added to the rainfall in these results. Elaborate experiments were carried out on the water contents of the soil. It was found that the soil in its natural position could only be charged with water to the extent of 24 per cent. of its dry weight, and to this extent only in the top foot and immediately

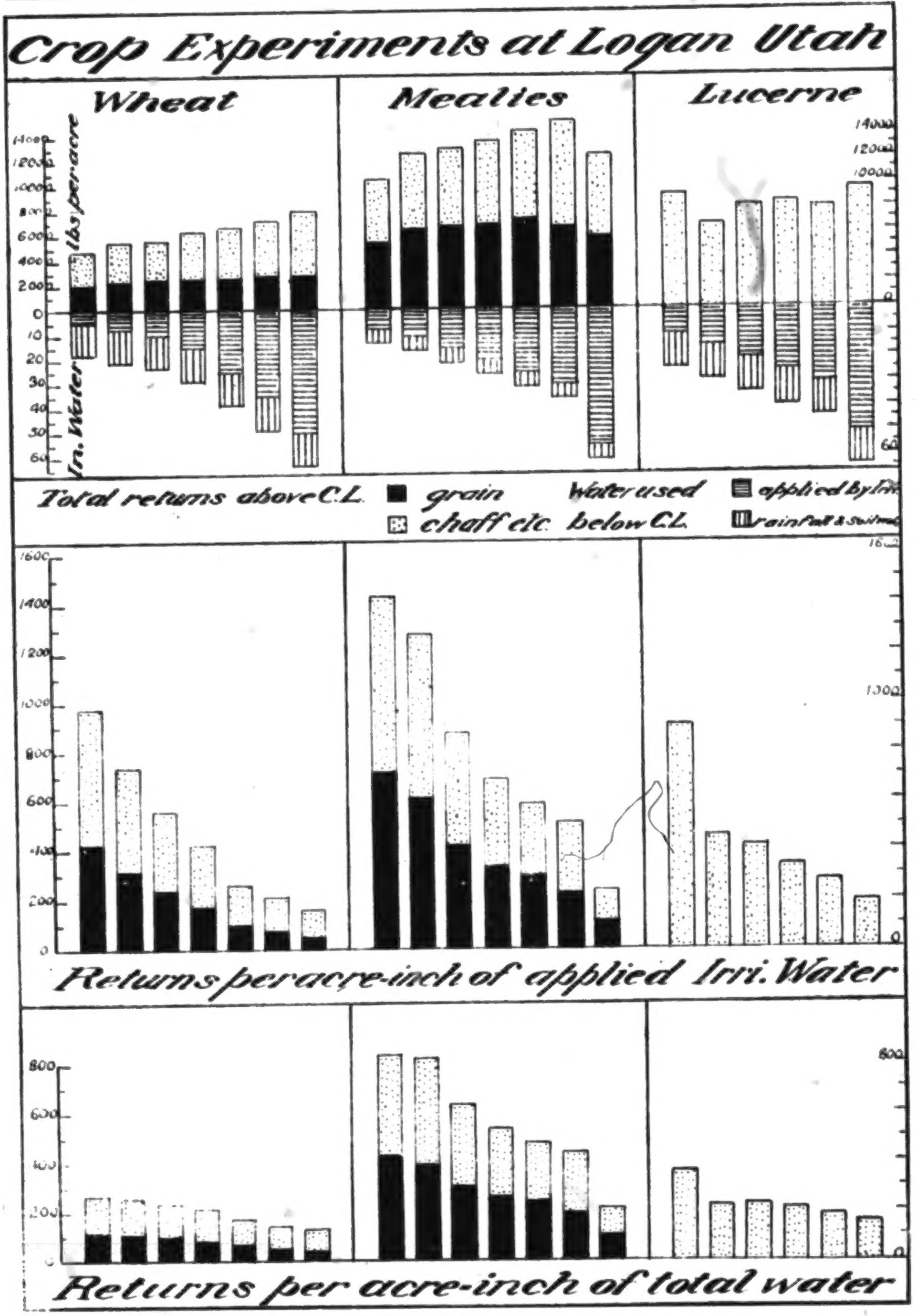

Crop Experiments at Logan Utah
Wheat
Mealies
Lucerne
Irr. Water
lbs per acre
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
14000
12000
10000
0
60
Total returns above C.L.
grain
chaff etc.
Water used below C.L.
applied by Irr.
rainfall & soil m
1600
1400
1200
1000
800
600
400
200
0
1600
1000
0
Returns per acre-inch of applied Irri. Water
800
600
400
200
0
800
0
Returns per acre-inch of total water

Fig. 23.

after irrigation, the percentage decreasing regularly in the succeeding feet even with the heaviest application, the maximum contents throughout the upper 8 feet being only 18 per cent. Just before irrigation the maximum proportion of water was in the fourth and fifth feet, but the differences were not great in the whole 8 feet. The average water-content of the upper 8 feet seldom fell below 10 per cent. before being supplied again with irrigation water.

When a 2½-inch watering was applied most of it usually remained in the top 8 feet, but with 5 inch and 7½ inch applications about one-quarter and one-third respectively usually passed below 8 feet, and this is considered beyond the reach of roots. As the total moisture in the top 8 feet is less at harvest than at sowing time, the loss in this period has been added to the rainfall and application to get the total used for the crop. The loss will vary with different crops. In the diagrams the soil-water used by lucerne and wheat is shown to be greatest, for they dry out the soil in a season much more than mealies and, indeed, than any other crop.

The diagrams show the crop returns. The quantities of water used are shown below the centre line of the top row of diagrams, and also apply to each of the other two rows.

Top row of Diagrams.

For wheat it will be noticed that the total return increased regularly from about 5000 lb. for a 5-inch application to 8000 lb. for a 50-inch application. The increase was greater in chaff than in grain, but grain also showed a regular though slight increase. This is contrary to the results of experiments in many other parts, which show a maximum grain return with a lower application than 50 inches.

Mealies show a maximum total yield with 30 inches and a maximum grain yield with 25 inches. The grain increases less rapidly than the rest of the plant when the application exceeds 15 inches.

The results for lucerne show the total for three crops in the season. These results are extraordinary, and also different from those obtained in other parts, which usually show a regular increase of return with an increase of water up to 55 inches. Here the maximum return is obtained with 55 inches, but it is only a very little more than the return for 10 inches, and the intermediate waterings give smaller returns than these two extremes.

Other Diagrams.

The second row of diagrams gives the returns per acre-inch of applied irrigation water for applications corresponding with the top row. The bottom row of figures gives similar returns per acre-inch of total water (including rain and soil water). These diagrams make it very clear that in every case with a fixed supply of water much greater total returns are obtained by spreading it over the maximum area. Thus with wheat, if we have a total supply of irrigation water of only 50 acre-inches, we shall get nearly four and a half times as great a return if we put 10 inches over 5 acres than if we put 50 inches over 1 acre.

Where water is limited and land and labour are abundant and cheap it will therefore pay to spread the water as lightly as possible over the greatest area. Where the land is limited and water abundant a slightly bigger return of wheat will be obtained by giving a deep application (up to 50 inches). This practice, however, can not be recommended on account of the danger of leaching or swamping the land, and, as shown by experiments at this station, the greater the water used the less is the protein-content of the grain and the greater the ash-content. The protein-content is the measure of the food value of the grain, and the ash-content the measure of the exhaustion of the soil.

From the bottom row of diagrams it will be seen that 1 acre-inch of water gave total returns of from 120 to 820 lb. of grain and chaff. As an acre-inch of water weighs about 225,000 lb., we see that every pound of total produce uses from 275 to 1875 lb. of water. A part of this is lost by evaporation and penetration beyond the reach of roots, but the greater part actually passes through the plant by transpiration.

The above experiments were analysed further in an attempt to find out what was the best way to apply a given quantity of water as to time and proportion. These results are not of great value, seeing that no water was applied before sowing on account of the good rainfall. The best returns were given in the following way:—

Wheat.—(1) With 3½-inch total application per acre, a late watering gave more grain than an early one.

(2) With 6½ inches, 7½ inches, and 10 inches, two equal waterings.

(3) With 15 inches, three waterings in the order 3½ inches, 3½ inches, 7½ inches.

Generally, when the grain return was most the chaff return was least.

Mealies.—With 15 inches, the best grain return was with three waterings in the order 7½ inches, 5 inches, 2½ inches.

For lucerne, experiments were made to determine the much-discussed question as to whether better returns are obtained by watering immediately before or after cutting. A total of 25 inches was applied in four equal irrigations in both ways with the following results:—

Water applied.	Lb. cropped.			
	1st.	2nd.	3rd.	Total.
Just before cutting first and second crop and 15 days after each	4144	3484	2570	10,198
Just after cutting first and second crop and 15 days after each	3932	3474	2729	10,135

The difference is not very great in the total, though the former method gave a bigger first crop, which is held to be the best.

The following interesting results should also be noted:—

Irrigation by furrows gave a slightly less return than irrigation by basin-soakage.

The proportional weights of leaves, stalks, and heads of wheat were observed at different periods of growth and with different quantities of water, with the result that much water tends to produce leaf at the expense of the head, and a small application increases both heads and stalks, but gives less leaf.

Although the greatest loss from the soil by evaporation is in the first two days after applying water, cultivation on the fourth day after application conserved more moisture than on the second day after application, because the surface puddled, if cultivated too soon after irrigation.

CHAPTER IX

THE GREAT BASIN AND SALT LAKE AND THE TRUCKEE-CARSON SCHEME

THE GREAT BASIN AND SALT LAKE

FROM Logan to the next scheme which I inspected—the Truckee-Carson scheme in Nevada—is roughly 400 miles in a straight line slightly south of west and right across the widest part of the "Great Basin" of America. This Great Basin covers about 200,000 square miles, and includes the greater part of the States of Nevada and Utah. It lies between the two great mountain ranges, the Rocky and the Sierra Nevadas. It has no outlet to the sea, and all the waters falling within it drain into inland lakes, of which the Great Salt Lake of Utah is the largest. The mean annual rainfall over the area is less than 10 inches. The surface consists of broad valleys at an elevation of about 4000 to 6000 feet and narrow abrupt mountains, the whole area having very little vegetation and being more thinly inhabited than any other part of America.

The Great Salt Lake is crossed by the railway on trestles and banks—together about 30 miles long. It covers an area of about 2000 square miles, and its surface is about 4200 feet above sea-level. Its surface-level has varied considerably during the last seventy years, rising or falling in wet or dry cycles. It fell 16 feet in the twenty years before 1906, but has risen about 8 feet since then. As it has no outlet its waters have become exceedingly salt. The salubrity varies according to the season from 15 per cent. to 22½ per cent., which is from four to seven times the salubrity of the ocean. The salts are the same as in the ocean, and have roughly the same proportion to each other.

Towards the western part of the Great Basin the railway runs for a long way in the valley of the Humboldt River, which ends in Humboldt Lake and Carson Sink. The surroundings of this river very much resemble those of the Fish and Zak Rivers in the north-west of Cape Province. It is an intermittent river and runs through a flat several miles wide composed of a clayey soil thinly covered by low bushes very similar to those of the Zak River. White alkali patches show up frequently. Carson Sink, where the river ends, is a great barren salty flat exactly like the great "vloers" on the Zak River. Indeed, most of the Great Basin resembles in soil, elevation, and vegetation the north-west of Cape Province more closely than does any other part of America.

The whole of the Great Basin consisted, in former geological times, of two great inland seas called by geologists the Bonneville and Lahontan Lakes. The Great Salt Lake is a remnant of the former, which occupied the eastern portion, and the Carson Sink is a remnant of the latter lake, which was in the west and at the eastern foot of the great Sierra Nevada Range. The Carson River, on which is situated the next scheme to be described, also drains into the Carson Sink from the Sierra Nevadas.

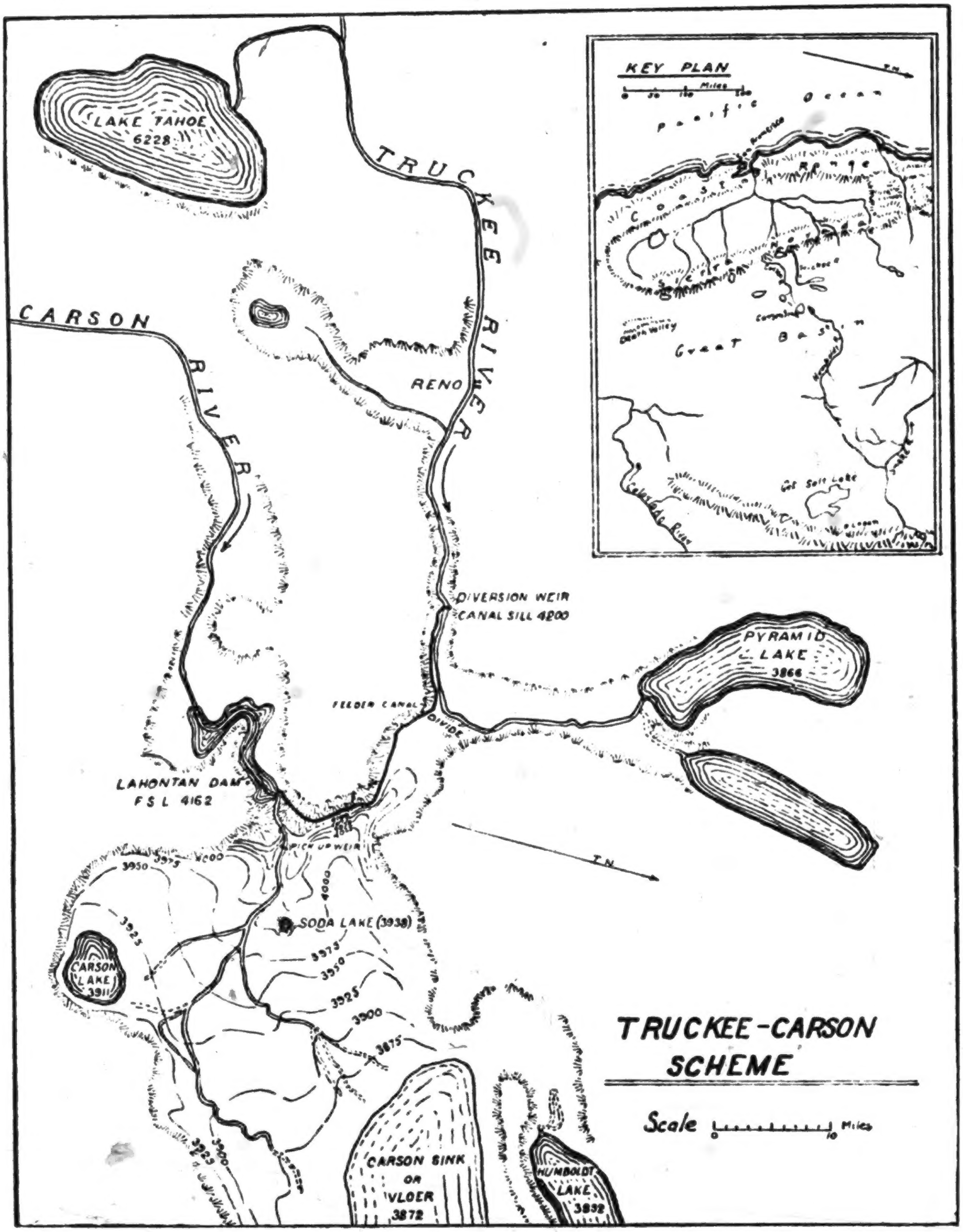
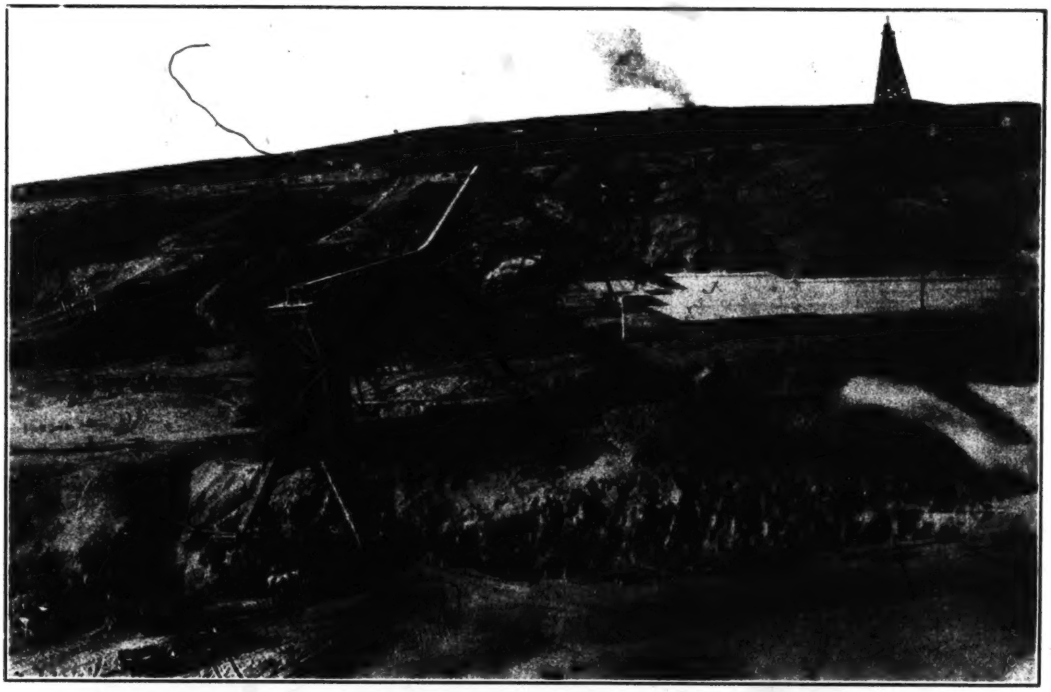
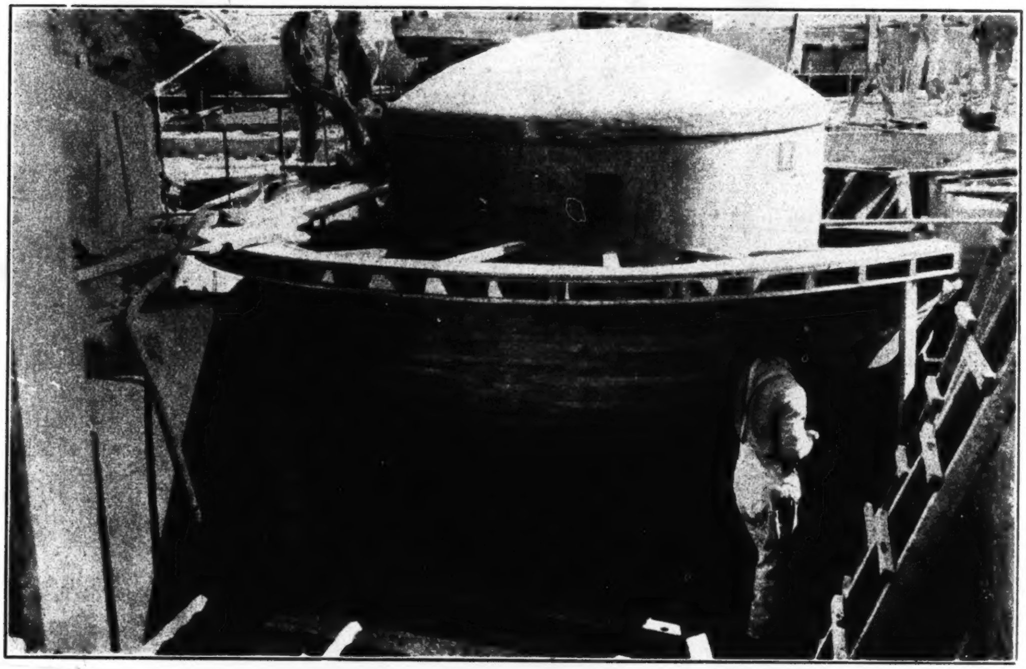

KEY PLAN
Miles
0 50 100 200
T.N.
Pacific Ocean
San Francisco
Coast Range
Sierra Nevada
Great Basin
Death Valley
Gt. Salt Lake
Colorado River
LAKE TAHOE 6228
TRUCKEE RIVER
CARSON RIVER
RENO
DIVERSION WEIR
CANAL SILL 4200
PYRAMID LAKE 3866
FEEDER CANAL
DIVIDE
LAHONTAN DAM
F S L 4162
PICK UP WEIR
SODA LAKE (3938)
CARSON LAKE 3911
CARSON SINK OR VLOER 3872
HUMBOLDT LAKE 3852
T.N.
TRUCKEE-CARSON SCHEME
Scale
0 10 Miles

Fig. 34.

TRUCKEE-CARSON SCHEME—Lahontan Dam.



(*a*) Plant on left bank. Conveyor-belt on trestles. Distributing hopper and shoots at ends. Earthwork of dam in foreground.

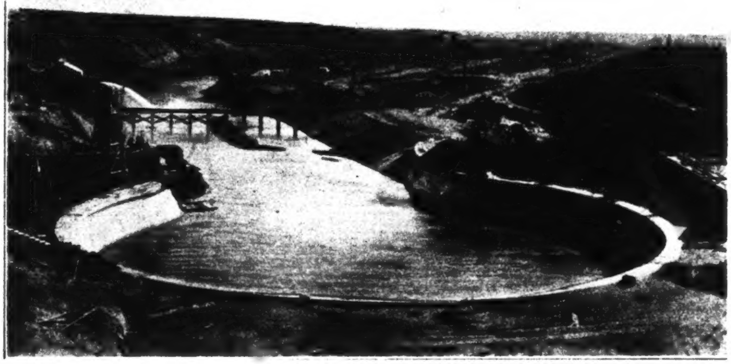


(*b*) Building Sill and entrance to Ring-valve.

Plate 11.

TRUCKEE-CARSON SCHEME.–Lahontan Dam.

(*c*) Looking up-stream during flood.



(*d*) Looking down-stream. Earthwork of Dam in foreground.

THE TRUCKEE-CARSON SCHEME

(United States Reclamation Service, Nevada)

This scheme is situated on the extreme west of the Great Basin and to the east of the Sierra Nevada Range. Although the lands are close up to this great snow-capped range, practically desert conditions prevail, the average rainfall over the irrigated area being only 4 inches, which is not more than in the driest part of South Africa, the north-west of Bushmanland.

The lands are situated at the end of Carson River on a delta formed where the river emerges from a canyon just before disappearing in Carson Sink. The level of the lowest part of the sink is 3872 feet, and the bulk of the lands have an elevation of from 3875 feet to 4025 feet.

Water Supply.

The Carson River rises in the Sierra Nevadas, and, although it has a drainage area of only 1500 square miles, it derives a large water supply from the snow of the great mountain range, the peaks of which exceed 10,000 feet in height. The mean annual discharge for eleven years, measured at a point about fifty miles above the lands (drainage area, 988 square miles), is 414,000 acre-feet, the maximum being 655,000 and the minimum 178,000. The highest recorded discharge is 20,000 cusecs. The type of monthly discharge is indicated by the following figures for 1906:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Cusecs ...	500	340	480	920	1950	2240	1860	420	130	200	320	480

This gives a total of nearly 600,000 acre-feet for the year, which is above the average. It will be seen that the flow is very small in August, September, and October, and quite insufficient for the direct irrigation of 200,000 acres—the area proposed for this scheme. There are also private irrigation schemes higher up the river with older appropriation rights for 32,000 acres. To supplement the flow of the Carson River, the Truckee River has been tapped. This river runs roughly parallel to the Carson River and ends in Pyramid Lake, the divide between the two rivers, about fifteen miles above the lake, being sufficiently low to allow of diversion (by means of a canal) of part of its waters into the Carson River.

It also derives its waters from the snow of the Sierra Nevadas and from Lake Tahoe, which is at an elevation of 6228 feet and has a mean depth of 1000 feet. It drains an area of about 1800 square miles above the point of diversion. Its mean annual discharge is 915,000 acre-feet, its maximum 2,220,000 and minimum 390,000. The maximum observed discharge is 9000 cusecs. The type of monthly discharge is indicated by the following figures for 1906:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Cusecs ...	860	800	1120	2850	3820	3360	2160	730	730	780	910	960

This gives a total of about 1,165,000 acre-feet for the year, which is above the average.

The diversion canal is designed to carry 1200 cusecs from this river to the Carson River.

It will be seen that the combined direct flow of the two rivers is insufficient in the latter part of the year for 200,000 acres, and storage is essential. This is being provided on the Carson River by the Lahontan dam now in course of construction, and on the Truckee River by raising Lake Tahoe.

Temperature.

The temperature over the irrigable area has varied from –15° to 103° F., but is usually between 0° and 100°. The summer is very similar to parts of our Karroo. Although the days are warm in summer, the nights are usually cool and the atmosphere is generally very clear.

Outline of Scheme.

Across the Truckee River a diversion-weir has been built and a feeder canal, thirty-one miles long, is constructed to carry 1200 cusecs from the Truckee to the Carson River. A small amount of irrigation is done directly from the feeder canal, but most of the water reaches the Carson River at a level above the spillway of the Lahontan reservoir. This reservoir, now in course of construction, will have a concrete-cored earthen dam 124 feet high, which will give a storage capacity of 290,000 acre-feet. The most interesting features are the artificial spillways, the core-wall, and the valves.

Below the reservoir the channel of the Carson River is used for five miles, and then, by means of a pick-up weir, the water is diverted through two main canals and a system of smaller canals along the ridges of the delta. Lake Tahoe will also be used for storage, and very cheap and simple works will give a storage of 750,000 acre-feet. After contracts had been allotted for this work, legal difficulties arose. The lake lies partly in California State, and on the complaint of owners along the lake in California the Californian Court forbade the work.

Detailed Works.

The Truckee Diversion Weir.

The Truckee diversion-weir consists of a series of sixteen gates between piers across the Truckee River. The gates are 5 feet wide and 10 feet high, in two parts, worked by the same screw, the top part coming into action only when the lower half is raised. Above the gates are flashboards giving 5 feet more discharge. The head gates to the feeder canal are square to the weir gates, and similar in design, but with only nine openings 5 feet wide. The first ten miles of the canal are through difficult country, being in the canyon of the Truckee River, which is narrow and has steep sides. In consequence, where the canal is in open cutting, the type-section adopted has a very great depth in proportion to width. The ruling dimensions are:—bottom-width 20 feet, side slopes 1 on 1 or 1 on 1½, full-supply depth 13 feet, and long. slope 1 in 6500. The excavation is over 50 feet deep in places. Three tunnels were required with a total length of over 900 yards. The slope in the tunnels is 1 in 1500. Of the ten miles, a total length of about 2⅓ miles is concrete-lined (with steeper side slopes) to reduce excavation and to prevent leakage through the porous rock. Where lined, the side slopes are 2 on 1, and the long. slope is 1 in 2400. The capacity of the canal is 1200 cusecs, but it has not carried more than 600.

Feeder Canal.

After the first ten miles the line of the canal is in fairly easy sidelong ground for the remaining twenty-one miles, the usual section being 14 feet bed-width, side slopes 1 on 1½, full-supply depth 13 feet, and long. slope 1 in 7000. An escape from the feeder canal is provided with radial gates 5 feet by 5 feet. These work under a head of 18 feet, and the weight of the gate is counterbalanced by weighted troughs.

At its end the feeder canal is 120 feet above the Carson River bed, and advantage has been taken of this drop to generate power for construction work on the Lahontan dam.

The Lahontan Storage Dam.

This dam is of very great interest in design and methods of construction, and as I saw it at a very favourable time during construction, I propose to describe it in considerable detail.

The chief features of interest in the design are (1) the artificial spillways providing stepped falls of reinforced concrete, the rock at the site being too soft to drop the water over it without protection; (2) the cut-off wall and method of grouting below it; (3) the drainage system;

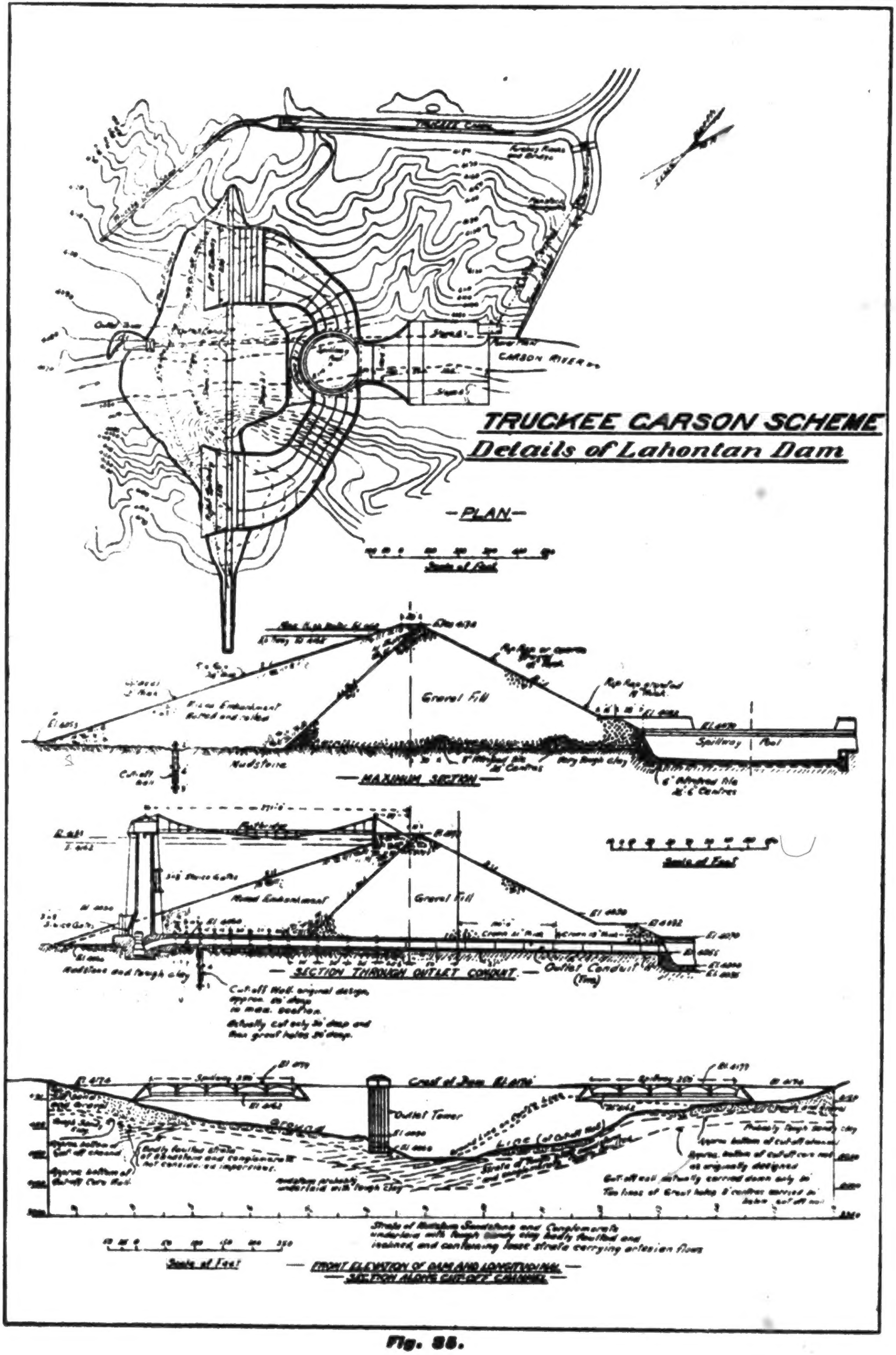

TRUCKEE CARSON SCHEME
Details of Lahontan Dam
-PLAN-
CARSON RIVER
Scale of Feet
Gravel Fill
Spillway Pool
Mudstone
Cut-off wall
-MAXIMUM SECTION-
Rip Rap or quarry
Rip Rap grouted
Gravel Fill
Rolled Embankment
Sluice Gates
Mudstone and tough clay
-SECTION THROUGH OUTLET CONDUIT-
Outlet Conduit
Cut-off Wall, original design, approx. 80' deep in max. section.
Actually cut only 30' deep and then grout holes 30' deep.
Scale of Feet
Crest of Dam El. 4170
Spillway 300'
Outlet Tower
Ground
Badly faulted strata of Sandstone and Conglomerate not considered impervious.
Mudstone probably underlaid with tough clay
Probably tough sandy clay
Approx. bottom of cut-off as originally designed
Two lines of Grout holes 5' centres carried below cut-off wall
Strata of Mudstone Sandstone and Conglomerate underlaid with tough sandy clay badly faulted and inclined, and containing loose strata carrying artesian flows
Scale of Feet
-FRONT ELEVATION OF DAM AND LONGITUDINAL SECTION ALONG CUT-OFF CHANNEL-

Fig. 35.

(4) the proportioning of the earth and gravel for the bank; (5) the novel ring-valves.

In construction the chief features of interest are (1) methods of grouting below the cut-off wall; (2) method of mixing sand and gravel for the earthwork of the dam and the method of conveying materials to the dam; (3) the use of sand-cement; (4) the travelling cables.

Locality.

The plan and longitudinal section in fig. 35 and the photos on plate 11 give an idea of the nature of the site of the dam. It is not a very favourable site on account of the softness of the surrounding formation, practically all of which is subject to easy disintegration and water erosion.

The gorge of the river is nearly a quarter of a mile wide at crest-level, which is 124 feet above the river bed. The sides are fairly steep up to crest-level, and from this level gentle slopes climb up to the higher hills, a couple of miles away. These upper ledges are usually covered by layers of silt, sand, and gravel (the remains of the old Lahontan Lake), which provide the materials for the dam. In the gorge and below the bed (as revealed by borings) the formation is softish rock roughly stratified. The strata have a variable dip up to 24 degrees, and are very much faulted and broken. They vary from mud-stone, conglomerate, and shale to sandstone, and have clay-layers and seams throughout. The whole formation is therefore easily penetrated by water. On such a heterogeneous, soft, pervious, and disjointed formation a solid concrete dam would be very unsafe, and consequently an earthen type with concrete core has been adopted.

Design.

The maximum height is 124 feet and the spillway-level is 12 feet below the crest. The up-stream slope is 1 on 3, protected by 2 feet of loose pitching over 1 foot of gravel. The down-stream slope is 1 on 2, protected by 1 foot of coarse gravel. The down-stream portion of the wall is constructed of gravel, which forms the bulk of the upper benches. Separated from this on the up-stream side by a 1 on 1 slope is the less pervious mixture of silt and gravel, both obtained from the upper benches on the left bank in separate layers. The proportioning of silt to gravel is not a matter which has been decided by an experienced eye, but is the result of most careful experiments carried out before and continuously during construction. The two qualities which were desired in the up-stream portion were heaviness and water-tightness. The latter is determined in a special laboratory by allowing water to pass, under a constant head of 3 feet, through a 3-foot vertical column, and thus measuring the percolation.

The following table shows some results:—

Mixture.	Specific Gravity.	Per cent. Voids.	Percolation. Gallons per acre per day.
Pure Gravel	—	—	400,000
85 per cent. Gravel 15 „ Silt ...	2·02	17·2	162,000
50 per cent. Gravel 50 „ Silt ...	2·05	18·0	20,000
Pure Silt	1·72	23·8	14,000

As a result of these tests, it was decided to use a mixture of equal parts of silt and gravel. This is considerably heavier than the pure silt, has a smaller percentage of voids, and is very little more pervious. A larger percentage of gravel made the percolation increase very rapidly. The silt and gravel are actually measured before mixing and putting them on the conveyor-belt, and samples of the mixture as it enters the dam are regularly tested for percolation in the laboratory.

The Cut-off Trench.

The cut-off trench is in the middle of the base of the up-stream part of the bank and therefore follows a curved line across the river. It was originally intended to carry this down to a maximum of 50 feet below the surface. It was found, however, on excavation in the lower parts near the bed, that the sides of the trench were not sufficiently self-supporting, and large quantities of water were tapped. Consequently, for a length of 250 feet, in and adjoining the river bed, the depth of the trench was limited to 30 feet, and below this depth the rock was made water-tight by grouting. Two lines (2 feet apart) of boreholes (3 feet apart) were to be sunk from the bottom of the 4-foot wide trench to a further depth of about 30 to 40 feet on the average. Actually, some of the holes were bored 80 feet deep, and one was carried to a depth of 100 feet. Before boring a hole, a 5-inch diameter pipe of 24-gauge galvanized iron was placed vertically over the spot where each hole was to be bored. The 30-foot trench was then concreted up round the pipes. The concrete filled up the whole excavation in the lower 15 feet, and in the upper half the concrete was restricted to a width of 4 feet by forms, the sides being filled with puddle later on. The drilling-bit then passed down each pipe and drilled a 2½-inch hole to a depth which was determined by examination of the core. Each hole, before being grouted, was tested for leakage for ten minutes under a water pressure of 127 feet from the Truckee Canal (just above full-supply level). The rate of disappearance of the water varied from 10 to 95 gallons per minute in the first holes tested, but as grouting proceeded the loss did not exceed 25 gallons in any hole. Generally speaking, the holes that showed the greatest leakage under this test took the largest amount of grout subsequently.

The first holes to be drilled, tested, and grouted were alternate ones (i.e. at 6-foot centres) or every fourth one (i.e. at 12-foot centres) in the front row. The intermediate holes in the front row were then bored and tested, and the rate of leakage was found to be considerably reduced. Only a few holes were actually drilled and grouted in the back row, as the leakage tests in them showed that the grouting in the upper row had proved very effective in reducing the leakage.

Grouting was done by means of a Caniff compressed-air apparatus (Tidewater Iron Works of Hoboken, N.J.). The air pressure at first was only 25 lb. (as with greater pressure air bubbles and cement appeared in the river), but was gradually increased to 100 lb. as the holes progressed. The best mixture was found to be 1 of neat cement to 7 or 8 of water. Where the grout got away very quickly the mixture was thickened to 1 to 1, and in some cases sand was added. Altogether, about 83 holes were drilled to an average depth of 32 feet, and 1174 sacks of cement were used, the average per hole being 14 sacks, though one hole took over 100 sacks.

Drainage of Base.

Drainage of the base is provided for in the down-stream portion of a length of 100 feet in the deepest part of the dam. Five lines of drain pipes at 25-foot centres and square to the axis of the dam run into the inspection gallery in the spillway pool. They are tiles of 8-inch diameter, and are laid with open joints in a trench 18 inches square filled with coarse gravel.

Spillways.

Two spillways are provided, each 250 feet long, one on each side of the river. These are unique in design. On account of the softness of the formation, natural spillways were impossible, and, consequently, reinforced-concrete drops have been provided for the whole height from full-supply level to the bed of the river. Both end in a huge circular reinforced-concrete pool at the toe of the dam in the bed of the river in which the discharge pipes of the reservoir also end. The right spillway is in a natural saddle, but the left spillway is in a portion of the dam where the crest-level of the spillway is about 60 feet above the

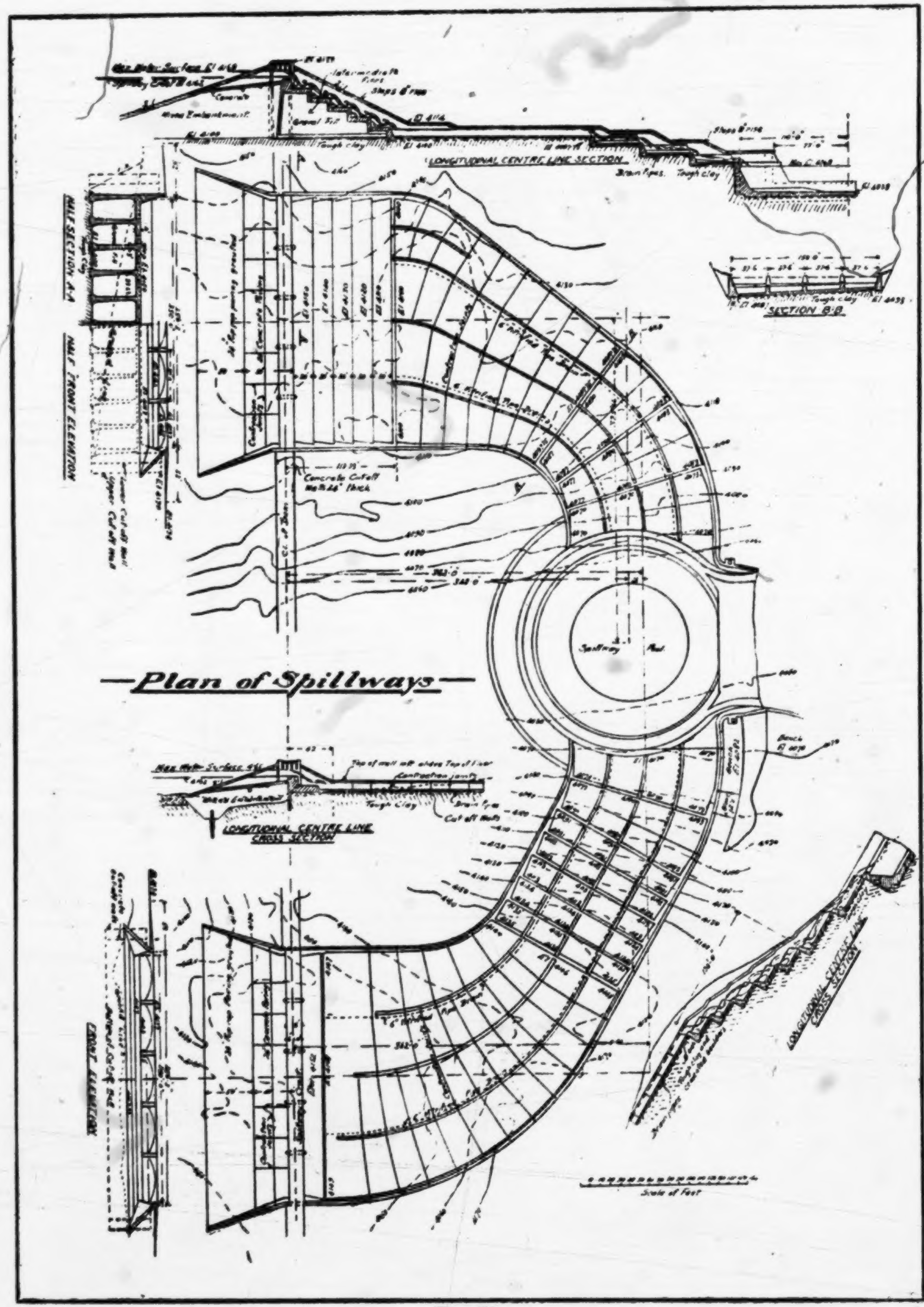
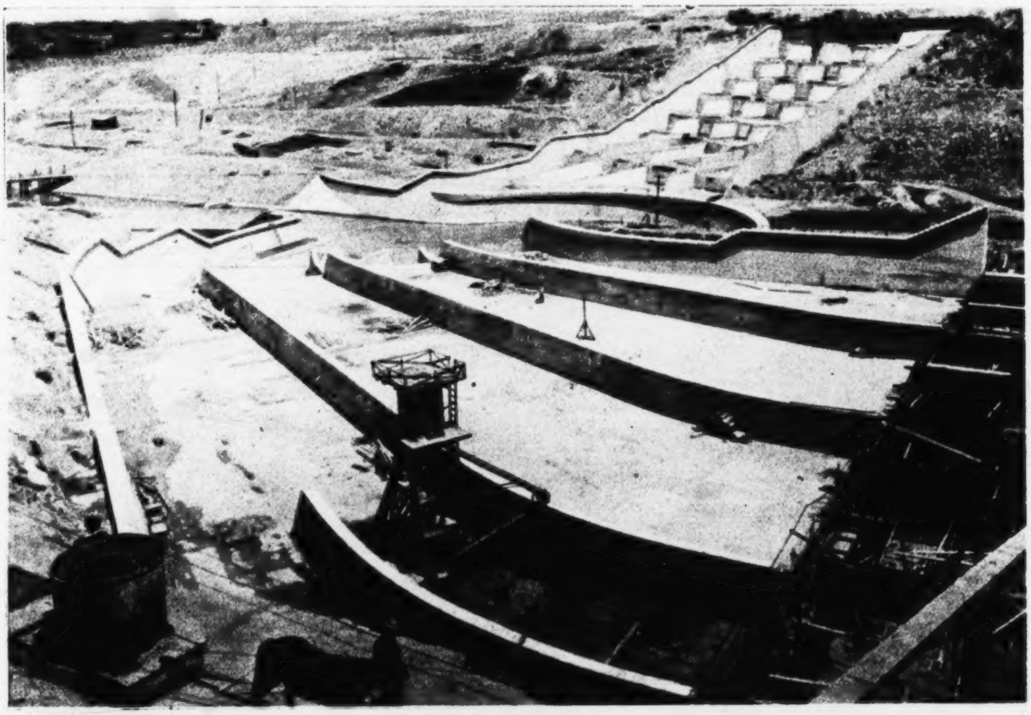
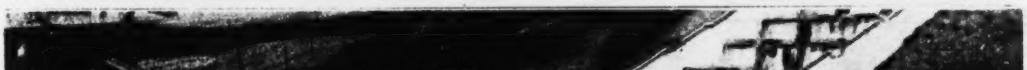

Plan of Spillways
LONGITUDINAL CENTRE LINE SECTION
Tough clay
Drain Pipes
SECTION B-B
HALF SECTION A-A
HALF FRONT ELEVATION
Concrete Cut off Walls 24" thick
Spillway Pool
LONGITUDINAL CENTRE LINE CROSS SECTION
Contraction joints
Cut off Walls
FRONT ELEVATION
Scale of Feet

Fig. 36.

TRUCKEE-CARSON SCHEME—Lahontan Dam.



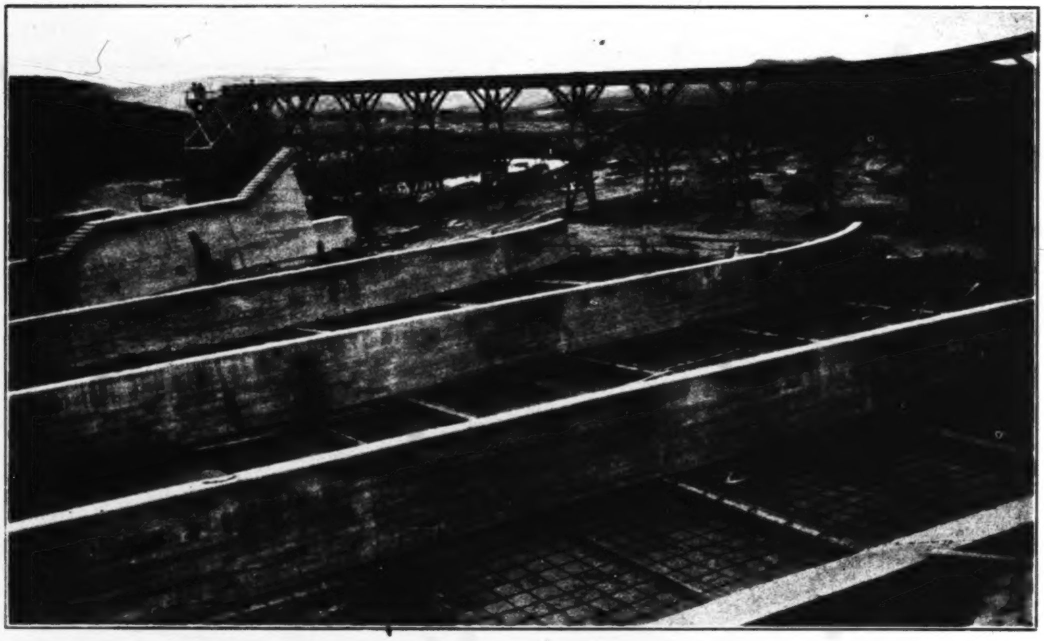
(*a*) Lower parts of both Spillways. Note concrete bucket on horse-truck and distributing hopper on movable tower.



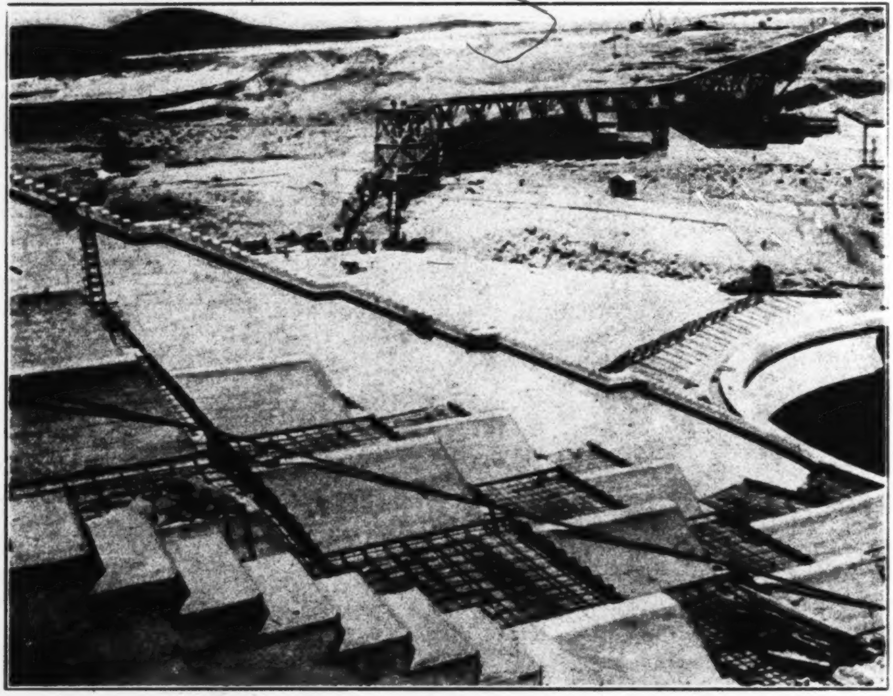
(*b*) Method of timbering for concrete of piers for drops at top of left Spillway.

Plate 12.

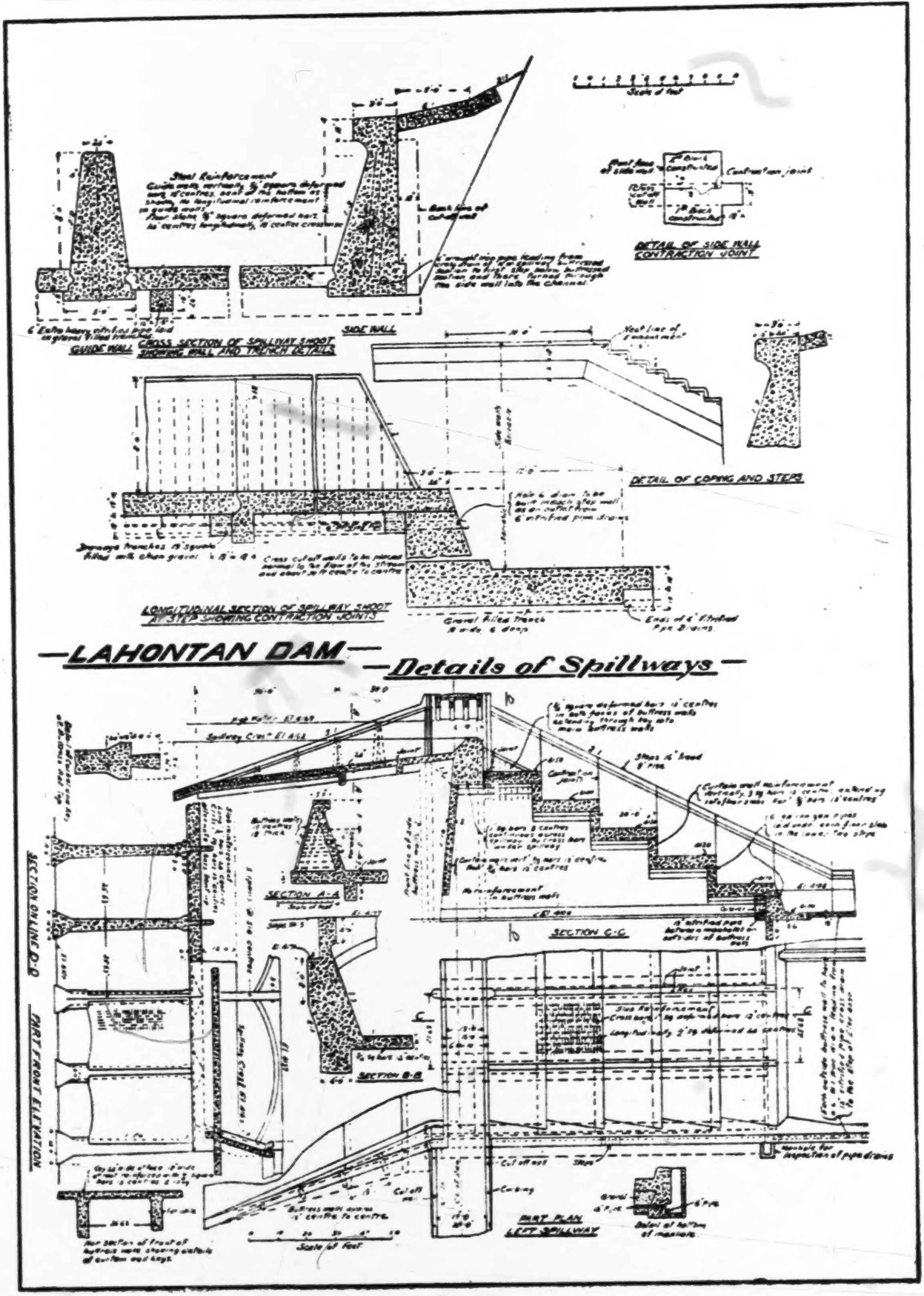
TRUCKEE-CARSON SCHEME—Lahontan Dam.



(c) Part of Left Spillway, showing guide-walls completed and floor-reinforcement and contraction-joints. Earth conveyor-belt on trestles in background.



(d) Lower drops of Right Spillway. Earth conveyor-belt on trestles in background.



Scale of feet
Steel Reinforcement
Back line of cut-off wall
DETAIL OF SIDE WALL CONTRACTION JOINT
Contraction joint
2nd Block Constructed
1st Block Constructed
SIDE WALL
GUIDE WALL
CROSS SECTION OF SPILLWAY SHOOT SHOWING WALL AND TRENCH DETAILS
Neat line of Embankment
DETAIL OF COPING AND STEPS
Drainage trenches 18" square filled with clean gravel
Cross cut-off walls to be placed normal to the flow of the stream and about 30 ft centre to centre
Gravel filled trench 8" wide, 6" deep
Ends of 6" Vitrified Pipe Drains
LONGITUDINAL SECTION OF SPILLWAY SHOOT AT STEP SHOWING CONTRACTION JOINTS
—LAHONTAN DAM—
—Details of Spillways—
Spillway Crest El 4162
Steps 16" tread 9" rise
Contraction joints
Curtain wall reinforcement
Buttress walls 15' centres 18" thick
SECTION A-A
SECTION B-B
SECTION C-C
No reinforcement in buttress walls
SECTION ON LINE D-D
PART FRONT ELEVATION
Slab Reinforcement
Cut off wall
Steps
Curbing
Cut off wall
Buttress walls spaced 15' centre to centre
Manhole for inspection of pipe drains
Detail at bottom of manhole
PART PLAN LEFT SPILLWAY
Hor. section of front of buttress walls showing details of curtain wall keys.
Scale of feet

Fig. 37.

natural ground. Each has an overflow weir and then a shoot with drops to the pool below. The details of these are shown on figs. 36 and 37. Below the overflow weir the work is dropped quickly so as to be in natural ground. The left weir requires six drops (of 10 feet each) to get to ground level. Thereafter curved concrete shoots and drops built into natural ground take the water to the pool. The curves are banked up on the outside, like a cycle track, and are provided with three guide walls. The shoot lengths have a gentle slope, and the drops are mostly 10 feet to 11 feet in height, and are placed where the ground-slope is steepest, seven being required in a series on the right spillway just above the pool.

Both spillway weirs have up-stream curtain-walls, 24 inches thick, laid on the earth bank and extending 90 feet up-stream at a slope of 1 on 10. The left spillway weir is practically an overflow weir, 60 feet high, built as a series of 10-foot drops. The whole is supported on piers spaced nearly 26 feet apart and resting on the tough clay foundation, the space between the piers and under the steps being filled with gravel. Separating the gravel-fill from the less pervious part of the bank, is a steeply sloping curtain-wall 24 inches thick. This is pierced at the bottom to allow seepage to be carried in drains through the gravel and discharged into the shoot below.

The floors and guide walls of the shoots and drops are reinforced, but the side retaining walls are of plain concrete. The floor is not rigidly connected with the guide or side walls, but simply rests on footings, and has keys with oiled surfaces, so that no rigid joint is made.

Contraction joints are provided in the floor and side walls approximately every 30 feet, these being in the form of keys (as shown), the surfaces being oiled.

On the down-stream side of each joint is a cut-off wall running across the shoot and extending 2 feet below the bottom of the floor. Below the floor, immediately above the cut-off walls and contraction joints, are plain gravel drainage trenches, 18 inches square, running across the shoot. Two drains of 6-inch open-jointed tile, laid in 18-inch square gravel trenches, run parallel to the length of the shoot, tapping each of the cross gravel drains and discharging through the vertical wall of the drop below.

Details of the spillway pool are shown on fig. 38. It has a diameter of 220 feet, and is 30 feet deep. It discharges to the river through an opening 10 feet above the floor and 120 feet wide. The

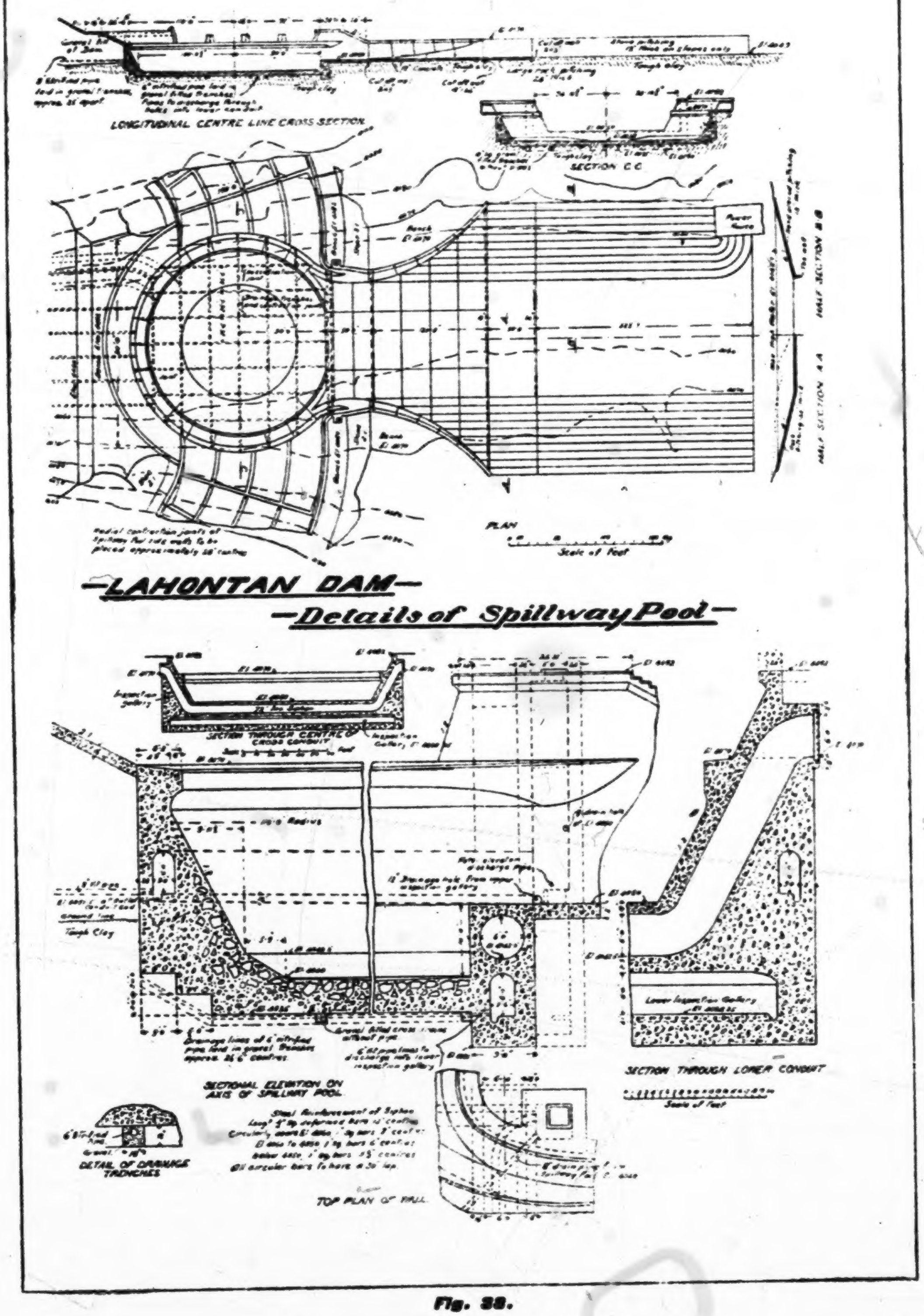

LONGITUDINAL CENTRE LINE CROSS SECTION
SECTION C.C
HALF SECTION B.B
HALF SECTION A.A
PLAN
Scale of Feet
Radial contraction joints of spillway pool side walls to be placed approximately 35' centres
—LAHONTAN DAM—
—Details of Spillway Pool—
Inspection Gallery
SECTION THROUGH CENTRE OF CROSS CONDUIT
Tough Clay
Ground line
Lower Inspection Gallery
SECTION THROUGH LOWER CONDUIT
Scale of Feet
SECTIONAL ELEVATION ON AXIS OF SPILLWAY POOL
DETAIL OF DRAINAGE TRENCHES
TOP PLAN OF FALL

Fig. 38.

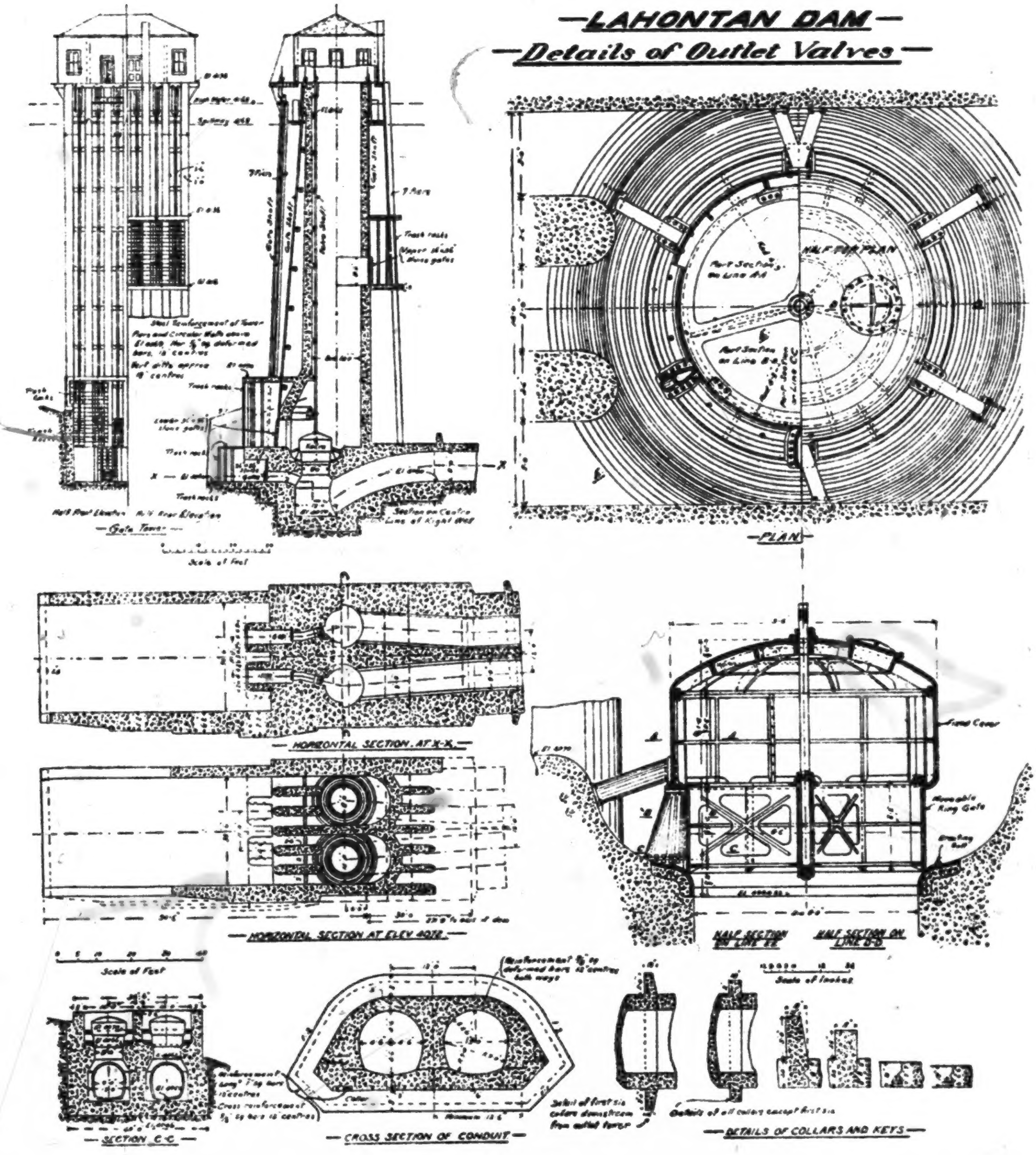

—LAHONTAN DAM—
—Details of Outlet Valves—
Spillway 458
Steel Reinforcement of Tower Piers and Circular Walls above El 4xx0, Hor. ⅝" sq. deformed bars, 18" centres
Vert. ditto approx. 18" centres
Trash racks
Trash racks
Upper 30x48 sluice gates
Lower 30x48 sluice gates
Gate Shaft
Gate Shaft
Relief Shaft
7 Bars
7 Bars
Half Front Elevation
Half Rear Elevation
—Gate Tower—
Section on Centre Line of Right Wall
Scale of Feet
Part Section on Line A-A
Part Section on Line B-B
HALF FOR PLAN
—PLAN—
HORIZONTAL SECTION AT X-X
HORIZONTAL SECTION AT ELEV. 4072
Fixed Cover
Movable Ring Gate
HALF SECTION ON LINE E-E
HALF SECTION ON LINE D-D
Scale of Feet
Reinforcement ⅝" sq. deformed bars 18" centres both ways
Reinforcement Long'l ⅝" sq. bars 18" centres
Cross reinforcement ⅝" sq. bars 18" centres
Collar
—SECTION C-C—
—CROSS SECTION OF CONDUIT—
Scale of Inches
Detail of first six collars downstream from outlet tower
Details of all collars except first six
—DETAILS OF COLLARS AND KEYS—

Fig. 39.

floor thickness varies from 5 feet at the sides to 2 feet 6 inches in centre. The floor is divided by contraction joints into slabs about 26 feet square. Drains run under the joints and carry the seepage water to wells at the ends of the outlet length.

An inspection gallery runs round the pool inside the side wall, and the five drains under the base of the dam drain into this, so that their discharge can be measured. All seepage water drains into wells at the ends of the outlet length, from which it is pumped into the river. Within the outlet wall part of a syphon is built to carry water from the Truckee canal across the river.

Outlet Valves.

The design of the outlet valves is unique. They are of the hollow-cylinder or ring type which eliminates friction due to one-sided water-pressure. They resemble the ring valves of water turbines. We have noted a somewhat similar type on the Oakley dam, where the water enters a tower on opposite sides through two openings, behind which a circular ring works vertically. We shall also describe a similar type on the Yuma scheme at the entrance to the Colorado River syphon. In the latter the entrance end of the syphon forms a circular rim in a horizontal plane. A hollow cylinder moves vertically over the rim. When the syphon is closed the bottom of the cylinder rests on the rim and the open top is above full-supply in the canal, so that no water can enter the syphon. As soon as the hollow cylinder is lifted water runs into the syphon evenly from all sides between the bottom of the cylinder and the rim. In the case of the syphon the height of water in the supply-canal is very small. For a high dam it is impossible to have such a length of movable hollow cylinder as will reach above full-supply in the reservoir.

To modify the principle for high dams a short length of hollow ring is made to move up and down inside a fixed cylinder with closed top, so that no water can get over the top of the ring, which is worked by a rod passing through a packed opening in the top of the fixed covering cylinder. A similar principle is found in the ring regulators of turbines. Fig. 39 shows the details. There are two of these valves with 8 feet 6 inches diameter cast-iron rings, each at the bottom of a separate well in a common tower. The ring is 3 feet 2¼ inches high, and works over an opening of 8 feet diameter with cast-iron rim, on which the tapered end of the ring makes a water-tight joint when the gate is shut. The covering cylinder is supported and fixed to the masonry and rim by six stout pillar castings. The ring is worked by a 4-inch rod passing through a stuffing-box in the centre of the cover.

A manhole is also provided in the cover. The masonry approach to the ring is made bowl-shaped, with a smooth curve all round so as to admit the water evenly (see photo B, plate 11). Water is admitted to the tower above the ring through two sets of openings. These have sliding gates, but will probably be closed only in emergency or when the water pressure is equal on both sides, the ring valves being used for most of the regulation. A small 3 feet × 3 feet scouring valve also works below the ring valve, probably to keep the approach to the ring valve clear. After passing the ring valve the water drops vertically into a 12-foot pit, which provides a water cushion. Each valve feeds a pipe of 9 feet diameter passing through the dam and discharging into the spillway pool. The details of the pipes and cut-off collars are shown on fig. 39. All the gates are operated by electrically driven oil-pressure rams in the house at the top of the tower, a footbridge connecting the latter with the dam.

Methods and Materials of Construction.

Electric power is supplied by the 125-foot drop from the Truckee canal. Two Pelton-Francis turbines are directly connected with dynamos, each of which generates 500 killowatts at 2300 volts, 3-phase, 60 cycles.

Earthwork. Suitable silt and gravel are found in abundance within a quarter of a mile of the dam at a convenient elevation on the bench on the left bank. The silt overlies the gravel bed in a thin layer 1 foot to 4 feet thick, and has to be removed first. This is done by a dragline excavator (56-ton electric Bucyrus, 1½ cubic yard bucket, 60-foot boom), which drags the silt-covering from a great distance into heaps near the truck line, and from these heaps a Marion steam shovel (35-ton, 1½ cubic yard dipper) loads into 4 cubic yard (Peteler) side-dump trucks. The gravel is excavated by an electric shovel (Bucyrus, 60-ton, 2 cubic yards) and loaded directly into the side-dump trucks. The trucks are drawn by 12-ton (Porter) locomotives on endless circular tracks to the mixing plant which is on the bench about 200 yards from the end of the left spillway. The sand and gravel are tipped separately into two long hoppers—running parallel to the river and close to each other—110 feet long and of 1000 cubic yards capacity. The trains run on top of these hoppers and dump as they run. The two hoppers are each V-shaped, and combined are W-shaped. To mix the gravel and silt in proper proportions (usually half of each), and to convey the materials either mixed or separately to the dam, the Stephens-Adamson system of belt conveyors has been adopted. Twelve horizontal sliding doors work under openings in the bottom of the long hoppers. These doors release the materials by oscillations caused by cams operated from eccentrics on a common shaft. The eccentrics are adjustable, so that the length of stroke can be regulated. After passing the doors the material drops to a 36-inch conveyor-belt running the full length between the silt and gravel hoppers. By adjusting the stroke of the reciprocating doors the gravel and silt can be put on the belt in any desired ratio. This 36-inch belt delivers at the end of the hoppers on to a 30-inch conveyor-belt which carries the material 925 feet on high trestles to the distributing hoppers well over the dam (photos 12 and 11, A). This belt is driven by a 100-horsepower motor. From the distributing hopper two inclined metal-lined shoots deposit the earth into horse-drawn bottom-dump wagons (Studebaker, 1¼ cubic yard), which dump it on the dam where required. It is then spread by harrows and Fresnos into thin layers, sprinkled by hose from a pipe system deriving water from Truckee canal, and rolled by a 10-ton traction engine. The unmixed gravel for the back of the dam is conveyed in the same way as the mixed material, but on other days. The capacity of the belt is 300 cubic yards per hour.

The gravel for concrete is dumped from the trucks to a 30-foot long extension of the long hoppers, from which an 18-inch conveyor-belt (35-horsepower) carries it 400 feet to the screening plant, which separates it by rotaries (3½ feet by 3 feet diameter) into three separate bins containing sand under $\frac{3}{16}$ inch and gravel of two sizes—$\frac{7}{8}$ inch and 2½ inch. From these bins proper proportions are measured on to an 18-inch belt 150 feet long, which, after receiving the measured cement, discharges into the mixer.

The excavation for the spillways was done by two 35-ton Marion revolving traction steam shovels with 1¼-yard dippers. These were very effective and worked their own way down from the top step to the bottom.

Concrete.

Sand-cement is used on this scheme with a plant similar to that used at Arrowrock. The same fine silt which is used for the up-stream portion of the dam is mixed with an equal quantity of cement, and the mixture is ground to form sand-cement. The silt is of an exceedingly fine, almost flowery, nature, and consists of about 70 per cent. of fine silicious sand and 30 per cent. of a clayey material composed mostly of silica and alumina compounds. About 9 to 15 per cent. of this silt in its natural state passes a 200-sieve, and the mixture of this with cement is ground so fine that 83 per cent. passes a 200-sieve. The usual concrete mixture is 1 sand-cement to 2½ sand to 6½ gravel, the latter consisting of roughly equal quantities of the ⅞-inch and 2½-inch sizes. As most of the concrete work is in narrow reinforced walls it is found that the sand-cement mixture does not work quite so easily as at Arrowrock (where the concrete work was in big masses), its handling being rather "dead," though on the whole it is successful and economical. One 1½ cubic yard Smith mixer is used (30-horsepower). From the mixer the concrete is shot into a bottom-opening bucket (2½ yards) on a truck which is drawn under the cableway by a horse. From the cable the bucket dumps into a hopper (3 yards) carried by a movable tower, and from this open shoots deposit the concrete where required (see photos A and B, plate 12). The timber for the concrete in the high walls is shown in photo B. Next the concrete horizontal 8 inch × 2 inch boards of Oregon pine are used; 6 inch × 2 inch uprights, spaced 2 feet 6 inches, are outside these on opposite sides; wires hold the uprights together and temporary 6 inch × 2 inch struts inside hold them apart. The wires are embedded in the concrete. Horizontal walling pieces 6 inches × 4 inches are at 4 feet intervals with ½-inch bolts through the concrete. It is found that, with sand-cement, the top corners of the concrete tend to chip off on setting, and to avoid this the wires have to be cut about twelve hours after depositing concrete. On account of the great space over which the concrete work is spread along the length of the river it was decided to have a cableway capable of movement up and down stream. The cableway (Lidgerwood) has a span of 1600 feet, and is supported by movable towers 100 feet high. The towers move on wide rails parallel to the river for a distance of 800 feet, and are very heavily balanced. The cable is operated by a 300-horsepower motor having a lifting speed of 250 feet per minute and a travelling speed of 1200 feet per minute, and the fall rope is carried by patent carriers. It can lift 10 tons, and actually lifted the parts of the Marion shovel from the river bed. It also lifts the concrete distributing towers from place to place.

The total estimated quantity of concrete is 75,000 cubic yards, of which 57,000 are in the spillways. The total is only about one-seventh of that at Arrowrock, so that the saving in using sand-cement is not so great as on that dam.

The whole quantity of earthwork and gravel in the dam is 730,000 cubic yards. The whole excavation is 330,000 cubic yards, of which over half is for the spillways.

The cost is estimated at one and a half million dollars.

Pick-up Weir.

The pick-up weir across the Carson River is five miles below the Lahontan dam, and in general arrangement roughly resembles the diversion-weir on the Truckee River. Two main canals start from the weir, one on each side of the river. The head-gates are of the movable-weir type, i.e. in order to open the canal the gates sink down below sill-level on the up-stream side of an overflow-weir, the water flowing over the top of the gates. Each gate is 17 feet wide by 5 feet high and has rollers. It is operated by two screws and worm-gearing from above.

Canals.

The main canal on the south has a capacity of 1500 cusecs, and the main canal on the north has a capacity of 400 cusecs. As will be seen from the contoured plan the fall along radial lines of the delta is roughly 6 feet per mile. The main canals run along the high ridges near the old river channels. Six feet per mile is too steep a slope for main canals, and consequently many drops are necessary. On the south main canal a drop of 26 feet has been given at one place near the head, and this is used for power purposes. The distributaries and minors follow small radial ridges throughout the area, and are designed for velocities of 1⅔ to 2 feet per second for capacities from 15 cusecs to 100 cusecs respectively. The larger structures are of concrete, but the smaller ones are of Californian redwood, which is cheap and stands water well.

Soils, Slopes, and Drainage.

About one-third of the whole area is a sandy loam of excellent physical texture, as the following analysis will show:—

Fine Gravel.	Coarse Sand.	Medium Sand.	Fine Sand.	Very fine Sand.	Silt.	Clay.
2·1	11·2	9·4	36·1	18·1	13·3	9·6

About one-third of the whole area is a very much heavier and more compact soil, containing over 50 per cent. of silt and clay. The remaining third is very sandy, being composed mostly of very fine sand, in some places forming dunes. In fact, on account of the strong prevailing winds a thin covering of sand is found over much of the whole area. The surface is, to the eye, generally even, especially where the soils are heavier, but in the sandy parts hummocks are frequent and require levelling.

Alkali is present in most of the soils, being strongest in the heavier low-lying soils. On half of the whole area the percentage of alkali is less than 0.2, on quarter of the area it is between .2 and .4, and on the remaining quarter it is above .4 per cent. The alkali is usually the white variety, black alkali not being very noticeable. In this connection mention should be made of the remarkable Soda Lake, the position of which is shown on the plan. It occupies the cup of an old volcanic crater, the rim of which rises nearly 100 feet above the surrounding flat. The water surface in the crater is about 60 feet below the surrounding flat or 160 feet below the rim, and the depth of water is as great as 150 feet. There is no surface inlet or outlet to the lake, the rim running completely round the lake high above the surrounding ground. Soda for commercial purposes was manufactured here, but the surrounding irrigation caused the water surface to rise 9 feet in ten years and drowned out the works.

The general surface slope over the greater part of the delta is roughly 6 feet per mile, which is very flat for irrigation purposes. Consequently, where the soils are heavy, the basin-soakage method of irrigation is largely practised (as at Minidoka). Here, too, the levelling is not done very thoroughly, and in one field I saw water standing as deep as 1 foot at one end to cover high patches in other parts of the field. Many basins are not provided with gates nor supplied with water directly from a furrow, and a string of basins is often wetted one after the other from the same gate—a method very wasteful of water.

The water-table has been gradually rising in spite of the construction of about 50 miles of shallow open drains in the hollows between the ridges on which the distributaries run. These shallow drains have not succeeded in removing the danger, which is very great here on account of the prevalence of alkali. At present a large area in the east and south-east is in great danger, the water-table having risen to within 4 feet of the surface. Consequently about six miles of tile drains 8 feet deep are being constructed in this area. The drains are of 10-inch to 15-inch tiles at a slope of 1 in 1000, discharging either into an open cut or into a sump, from which the water is pumped electrically (as at Minidoka).

Crops.

A total area of 36,620 acres was irrigated in 1912. Of this area over three-quarters was occupied by lucerne and pasture of native grasses, the latter occupying 15,000 acres. Cereals are next in importance, and small areas are occupied by potatoes, sugar beets, orchards, and gardens. A sugar factory has been opened on the scheme, and the area under beets will probably increase.

The average lucerne return was 2¼ tons per acre for three crops, and the value was $7 per ton in the stack. Considerable difficulty is often experienced in starting lucerne on account of the fine sand which is blown about by the strong prevalent spring winds. For this reason it is often sown with wheat as a nurse crop.

Settlement and Cost.

This was one of the first schemes undertaken under the Reclamation Act passed in 1902. Work began in 1903, and in 1906 the first irrigation was given under this scheme. The whole area contemplated by the scheme is 206,000 acres, of which 65,500 acres were in private ownership at the inception.

The area thrown open to entry of settlers has been limited until sufficient storage is provided on completion of the Lahontan dam. At present only 21,000 acres have been thrown open, which is mostly taken up. The area under water-right and rental contracts is now about 45,000 acres, more than half of which was privately owned. The maximum size of farm unit for settlers is 80 acres.

The building charge to settlers is $30 per acre, raised, I believe, from $22. The whole cost up to date, excluding Lahontan dam, has been over four million dollars, of which the Truckee River diversion cost one and a half million. The Lahontan dam is estimated to cost one and a half million dollars, and further extension of distributaries, etc., to complete the scheme another two and a half million dollars, so that the whole cost will be over eight million dollars, or about $40 per acre.

The maintenance charge was at first 60 cents per acre, but this has been raised to 75 cents. The actual cost in 1912 was $1¼ per acre irrigated, very little of which was for betterments. Gophirs (small burrowing animals) cause a great deal of trouble by making their holes through the canal banks and causing breaches.

The following extract from the Government brochure advertising the scheme is worth quoting:—

> "Do not make the mistake of thinking that you can come to the Truckee-Carson project without any capital or equipment, settle on a homestead, and make a success. Every new settler will need capital. You will need a house to live in, fences, a barn, provisions for family, and feed for stock for at least one year, farm machinery, tools, and seed. You will be unable to secure credit at the local stores as you are unknown and you have nothing to mortgage on a homestead. Consequently your capital should be sufficient to enable you to bring your farm to a paying basis, and this will require at least a year."

Distribution of Water and Duty.

For the distribution of water three superintendents, eight ditch-riders, and two head-gate watchers are required. A seven-day rotation system is practised, half the laterals being kept dry in alternate weeks. The irrigating streams in the basin-soakage method are larger than in the surface-flow or furrow methods—4 cusecs being a common stream and in some large basins as much as 15 cusecs is sometimes used.

For the irrigation of the 36,620 acres (apart from water returned to river) 169,267 acre-feet were diverted in 1912. This is 4⅔ feet over the irrigated area. About 2⅓ feet were delivered to the fields. The losses were observed in four canals to be 1.30, 1.51, and 0.52 cubic feet per day per square foot of wetted area of the canals.

CHAPTER X

CALIFORNIAN IRRIGATION

General Outline.

FROM the Truckee-Carson scheme to San Francisco is 300 miles by rail. The high Sierra Nevada Range is first crossed at such a height that the railway track has to be protected for some thirty miles by means of great wooden snow sheds in the form of tunnels. On the west the descent is on a long steep slope with pine forests and along valleys in the foot-hills dotted with beautiful Californian oak. The line then traverses the great central plains through the low-lying Sacramento valley to the great Bay of San Francisco.

The State of California (fig. 41, page 144) extends along the Pacific coast for a length of 800 miles with an average breadth of 200 miles—a total area of about 160,000 square miles, which is nearly as great an area as the Orange Free State and Transvaal combined, or of that part of the Cape Province south of the Orange River and west of Port Elizabeth.

From an irrigation point of view, the most remarkable feature of the geography of the State is the great central basin formed by the valleys of the Sacramento and San Joaquin Rivers. This low-lying fertile basin, with an average width of about forty miles, extends for some 400 miles parallel to the coast and is separated from it by the long continuous coastal range only pierced by the combined drainage of the great central basin at San Francisco through the famous Golden Gate. All along the east of the basin, and curving round to join the coastal range so as to completely enclose the basin with mountains, runs the great Sierra Nevada Range. This great range, with an altitude of 6000 feet to 14,000 feet, adds greatly to the value of the fertile basin by supplying a large number of streams with perennial water from the melting snows. Two great river systems run down the major axis of the valley, meeting at San Francisco Bay--the Sacramento River from the north and the San Joaquin River from the south. Both have a large number of strong tributaries coming down from the Sierra Nevadas at more or less regular intervals, not only supplying water for irrigation by direct flow, but giving wonderful opportunities for the development of electrical power.

The fertile basin is so flat and level that at 150 miles north and 150 miles south from San Francisco Bay the elevation is less than 300 feet above sea-level. If the sea were to rise 300 feet the basin would become a great inland sea over 300 miles long and 40 miles wide, surrounded, except where the ocean is joined at San Francisco, by enormously high mountains rising steeply from near the edge of the sea on the east and capped by snow.

It would be difficult to imagine a more favourable configuration of country than this for irrigation development, and California owes its prosperity largely to this wonderful natural arrangement. Nearly two-thirds (or ten million acres) of the total arable valley lands of the State and also about two-thirds (or two million acres) of the total irrigated area of the State lies in this great basin. By far the greater part of the irrigation is in the southern half of the basin, i.e. in the San Joaquin valley, the rainfall being greater in most parts of the Sacramento valley and sufficient for cultivation without irrigation. North of the basin the country is exceedingly mountainous.

The coastal range continues southwards beyond the great basin, rising to great heights in the San Bernardino Range near Los Angeles. Irrigation is practised here on the coastal streams, and particular reference will be made to the Santa Ana River irrigation which is of a very high class. Behind the coastal range and the Sierra Nevadas in the south-east are the great desert areas with very low rainfall and few streams. The Colorado River is the south-eastern boundary of the State, and it has been possible to use the river on a part of the desert (the Salton Sea) which lies below sea-level, forming the famous Imperial Valley scheme.

As a matter purely of geographical interest, mention might be made of the famous Death Valley, which, although far from the sea, and within seventy miles of Mount Witney, the highest peak in America (14,500 feet), is over 400 feet below sea-level.

Rainfall.

The rainfall decreases from north to south, and also from the coast inland. Thus along the coast near the northern boundary, the mean annual rainfall is 46 inches, at San Francisco 24 inches, and near the southern boundary only 10 inches. The coastal range catches up much of the moisture, and, consequently, the rainfall is less in the central basin, and in it also decreases from north to south. Thus, 150 miles up the Sacramento Valley, the rainfall is 26 inches, whereas at a similar distance south from San Francisco, in the basin about Fresno, the rainfall is only 10 inches. The Sierra Nevada Range still further reduces the moisture, and east of the great range very arid conditions prevail, the rainfall also decreasing from north to south. Thus we have seen that the mean rainfall at Truckee-Carson is 4 inches, while in the Imperial Valley in the south it is only 2½ inches. Over the whole area the rainy season is winter, by far the greatest part of the rain falling from October to May, the rainfall from June to September being usually almost negligible.

Temperatures.

California extends from latitude 42 degrees to about 32½ degrees, which corresponds with the Mediterranean between Rome and Alexandria, the southern limit also corresponding with the north of the Punjab in India. The Pacific Ocean has a great influence on the climate of California. The warm West Drift Current, after crossing the Pacific, strikes America at its northern boundary and the California branch then runs south along the west coast. This warm current makes the climate very equable.

Along the coast, from San Francisco southwards, the highest temperature is 101° F., the lowest about 30°, and the mean annual about 60°—conditions very much resembling those of Capetown. Away from the coast the extremes of heat and cold are greater. In the San Joaquin Valley, the temperature ranges from 120° F. to 16°, with a mean of 63°; and in the Imperial Valley from 128° to 18°, with a mean of 77°.

Peculiar conditions in California.

California stands apart from all the other States, not only in the greater extent of its irrigation, but in the way in which it has been developed. In most of the other States, land is only acquired in small parcels by actual settlement. In this State, however, under its former rulers (at first Spanish and then Mexican), large areas were given out in blocks of from 4000 to 25,000 acres, so that the "homestead" method of entry of land peculiar to other States could not be adopted largely here. In this respect the conditions resemble those of South Africa. Under these conditions, practically no Government reclamation work has been done, most of the development coming from private individuals or companies and co-operative irrigation districts, for which special provision has been made in the Wright Act. In irrigation law, too, the practice in this State is fundamentally different from that of most other States, a modified form of the old riparian law holding as against the more modern prior-appropriation laws of other States, in this respect also resembling South Africa.

I visited four schemes in this State. These are all south of San Francisco, and in order from north to south as follows:—

Schemes described.

(1) The Modesto-Turlock scheme on the Tuolumne tributary of the San Joaquin River. This is a successful irrigation district scheme including about 250,000 acres.

(2) The Fresno scheme, also in the San Joaquin Valley, deriving water from the King's River. This scheme is run by a private company and includes about 360,000 acres in the heart of the famous grape country.

(3) The Redlands scheme on the Santa Ana River near Los Angeles. This is a smaller scheme (about 22,000 acres) of a co-operative type different from the Modesto-Turlock type. It is of great interest on account of the methods adopted for economizing water. The irrigation is of a very high class, and expensive crops, such as oranges, are chiefly grown here.

(4) The Imperial Valley scheme in the extreme south. Nature has provided a huge basin mostly below sea-level and close to the great Colorado River. A canal easily diverts water from the river to cover an area of about 400,000 acres. This is a combined company and co-operative scheme. The conditions of soil, water, and climate on this scheme somewhat resemble those of the Punjab in India.

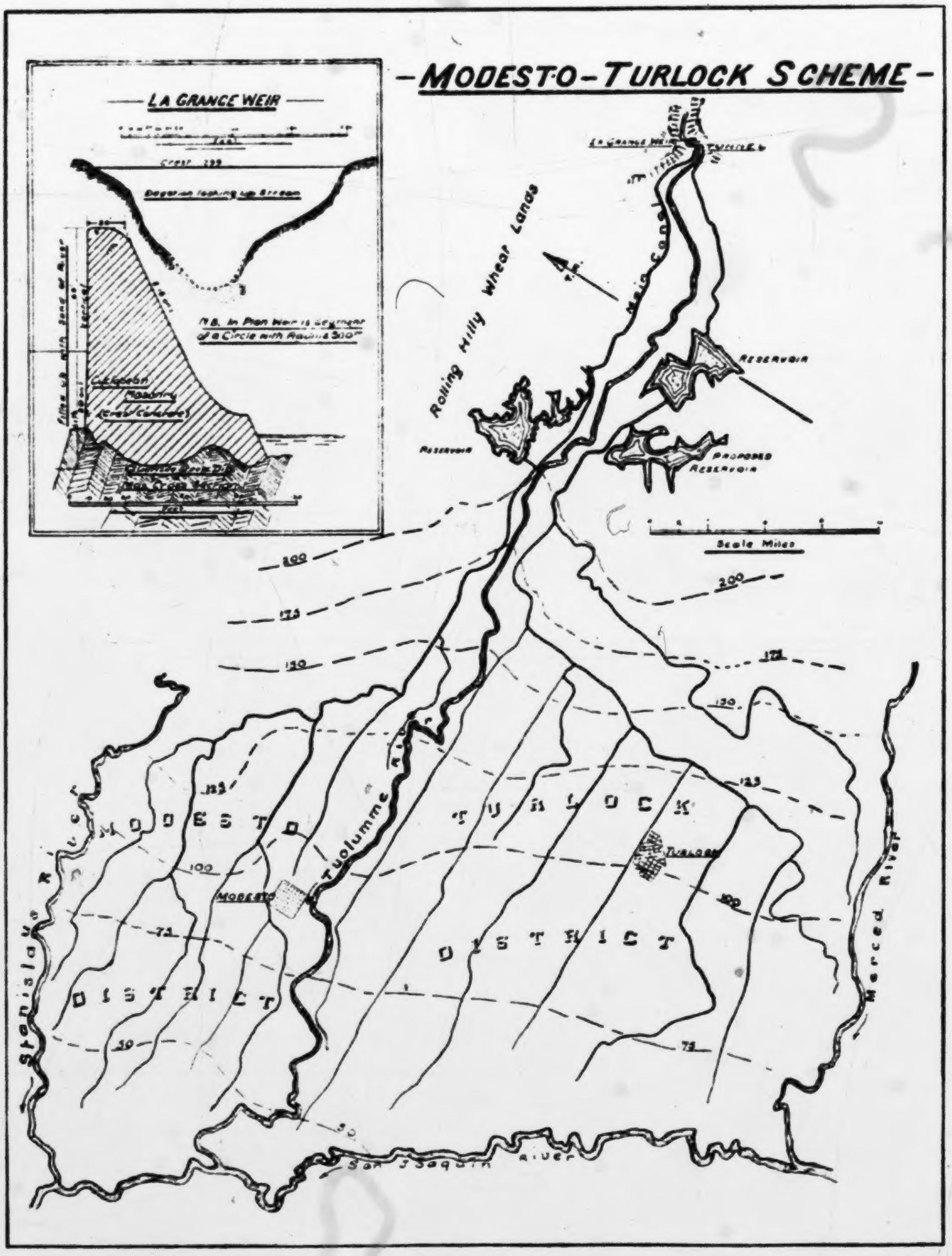

-MODESTO-TURLOCK SCHEME-
LA GRANGE WEIR
Crest 299
Elevation looking up stream
N.B. In Plan Weir is Segment of a Circle with Radius 300 ft
Cyclopean Masonry
La Grange Weir
Tunnel
Rolling Hilly Wheat Lands
Main Canal
Reservoir
Reservoir
Proposed Reservoir
Scale Miles
200
175
150
125
100
75
50
MODESTO DISTRICT
TURLOCK DISTRICT
Modesto
Turlock
Tuolumne River
Stanislaus River
Merced River
San Joaquin River

Fig. 40.

Plate 13.

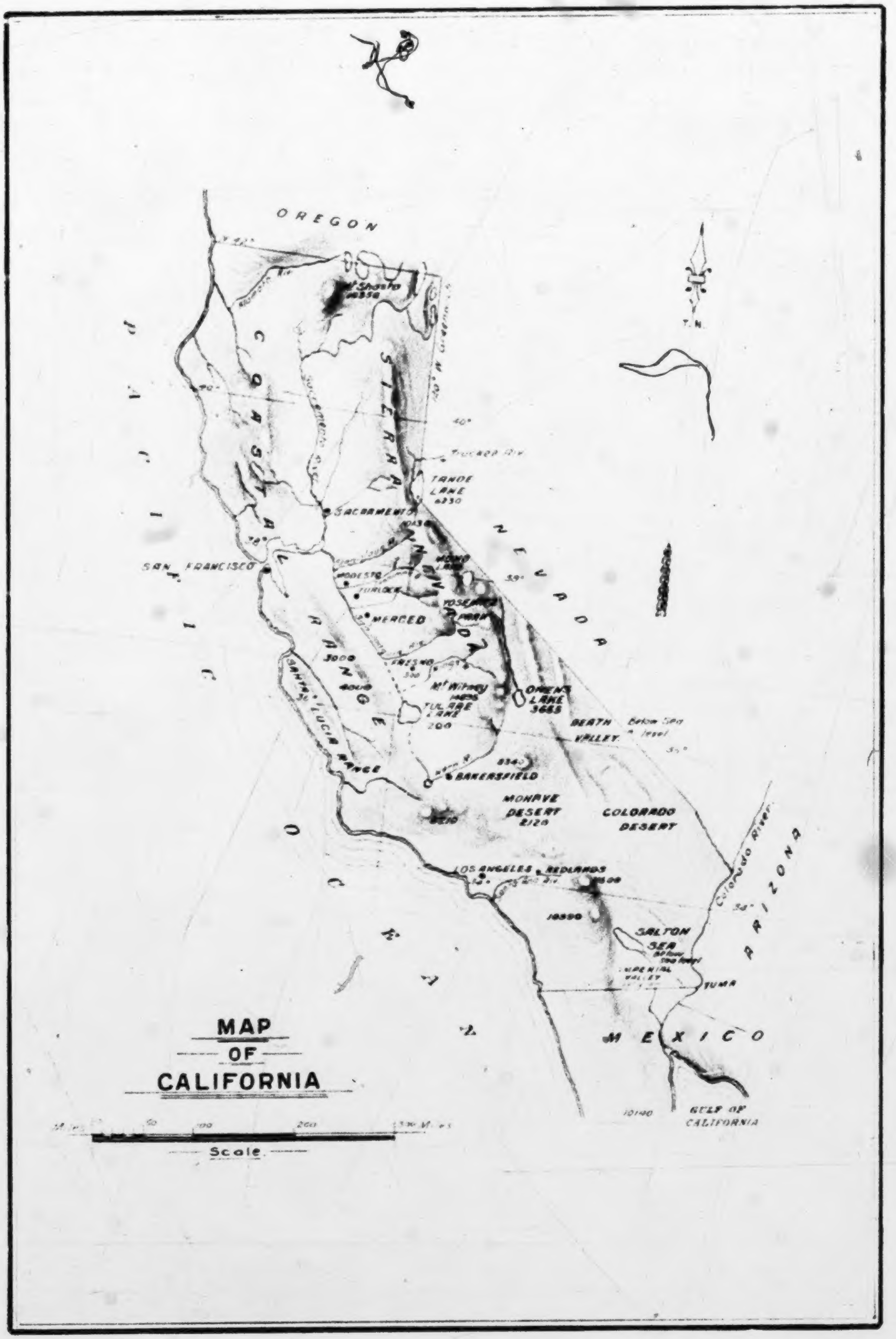
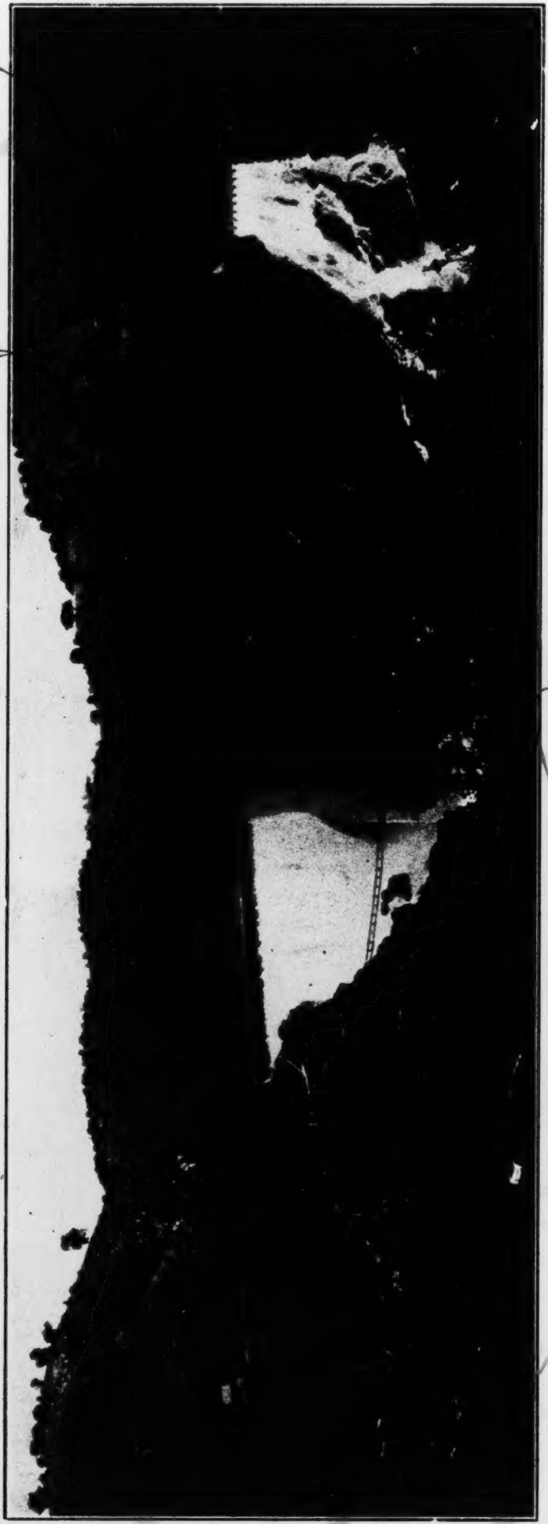

OREGON
Mt Shasta
14350
COAST RANGE
SIERRA NEVADA
PACIFIC OCEAN
40°
Truckee Riv.
TAHOE LAKE
6230
SACRAMENTO
SAN FRANCISCO
38°
NEVADA
MONO LAKE
39°
MODESTO
TURLOCK
YOSEMITE PARK
MERCED
3000
4000
FRESNO
Mt Whitney
14898
OWENS LAKE
3665
TULARE LAKE
200
SANTA LUCIA RANGE
DEATH VALLEY
Below Sea level
BAKERSFIELD
8340
MOHAVE DESERT
2120
COLORADO DESERT
8810
LOS ANGELES
REDLANDS
11500
10800
SALTON SEA
IMPERIAL VALLEY
Colorado River
ARIZONA
YUMA
MEXICO
10140
GULF OF CALIFORNIA
T.N.
MAP
OF
CALIFORNIA
Miles
50
100
200
Scale

Fig. 41.

Plate 13.

MODESTO-TURLOCK SCHEME—La Grange Weir.



(*a*) Showing both Canals concrete-lined, the Turlock Canal emerging from tunnel at spillway.

(*b*) Weir from left bank.

CHAPTER XI

THE MODESTO-TURLOCK SCHEME

Water Supply.

THIS scheme derives its water from the Tuolumne River, a tributary of the San Joaquin River, rising in the snow-capped Sierra Nevadas. The drainage area above the point of diversion is about 1500 square miles, and includes the famous Hetch Hetchy Valley which it is proposed to use for San Francisco's water supply.

The following is the mean discharge of the river at the point of diversion :—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Cusecs ...	1674	1795	2400	4039	7402	7179	2607	1028	439	364	702	705

The average yearly mean is 2526 cusecs.

The maximum flood was 59,800, and the minimum flow 69 cusecs.

As the whole area to be irrigated by the scheme is over 200,000 acres, it is obvious that storage is required for the latter part of the year.

Rainfall.

The mean rainfall is as follows :—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Inches ...	2·32	1·82	2·06	0·86	0·57	0·08	0·01	0·07	0·26	0·66	1·52	2·19

Total ... ... 12·42 inches.

From this it will be seen that most of the rain falls in winter, and the months June to September are practically rainless.

The temperature varies from about 30° F. to 110° F.

Outline of Scheme.

La Grange weir is built across the Tuolumne River, where it still runs in a deep narrow canyon in fairly high hills. Two canals start from the weir, one on each side of the river, for the Modesto district on the right bank and the Turlock district on the left bank. Both canals run close to the river for some twenty miles through rolling country of low hills. Storage reservoirs are provided on both canals in this upper reach. After passing through the rolling foothills, the San Joaquin plain is reached, and most of the irrigable lands are in this great level stretch of country. The assessed area in the Modesto district is 81,000 acres, and in the Turlock district 176,000 acres, and of this total about 225,000 acres are irrigable.

Engineering Works.

La Grange Weir. The La Grange weir is a very high overflow-weir built across the stream. The river is very narrow here, and at crest-level the width is only 280 feet. The weir has therefore been built in the form of an arch with a radius of 300 feet. The maximum section is shown on fig. 40 (see also photos, plate 13). The maximum height, in a huge pot-hole in the bed, is about 127 feet. It is built on a very hard stratified quartzite. The strata are very broad and dip up-stream at a very steep angle. A short distance down-stream the formation changes, and, instead of the hard rock, a finely-stratified slate is found with almost vertical dip. The pond above the weir was very quickly filled up with sand by the river. The weir was completed in 1903, and it cost about $543,000.

Canals. The Turlock district is about twice as large as the Modesto district, and the water is divided at the weir for the two districts in the ratio 2 : 1. The capacity of the Modesto canal is 750 cusecs, and of the Turlock canal 1200 cusecs, though both will be enlarged to a combined capacity of 3100 cusecs. The first five miles of both canals are through very difficult steep rocky formation. The Turlock canal starts in a long tunnel, and the Modesto canal, for several miles, is of concrete or concrete-lined, and about 16 feet wide and 8 feet deep with almost vertical sides. In the first thirteen miles the rolling hilly country is passed close to the river, and several deep valleys have to be crossed. Wood flumes were at first used, but these are now being replaced by hydraulic-fill banks, over 50 feet high, with culverts below and carrying the concrete-lined canal above. The manner of building these banks is as follows: The culvert for passing the side drainage is first built in the bed of the valley and the outside faces of the bank, with slopes of 1 on 2, are carried up above the rest of the work so as to form a settling pond into which the sediment-charged water is conveyed. The clear water is drawn off through a central vertical pipe coming up from the roof of the completed culvert. The pipe is raised in 1-foot sections as the work progresses. Where suitable soil lies at a sufficient height, it is sluiced by a nozzle-discharge under pressure, and runs direct to the bank pond. Where the soil is low but close, it is drawn by means of a dragline grader working on an endless rope to a dump over a flume carrying a stream which takes it up and transports it to the bank pond where it settles.

About the thirteenth mile on the south, 30,000 acre-feet of storage are provided in a valley by an earth dam 30 feet high. All the lands lie below the level of the reservoir, and the main canal is carried round the reservoir in a series of low drops. Some of these drops have been broken down to increase the grade and thus erode the canal to a greater capacity.

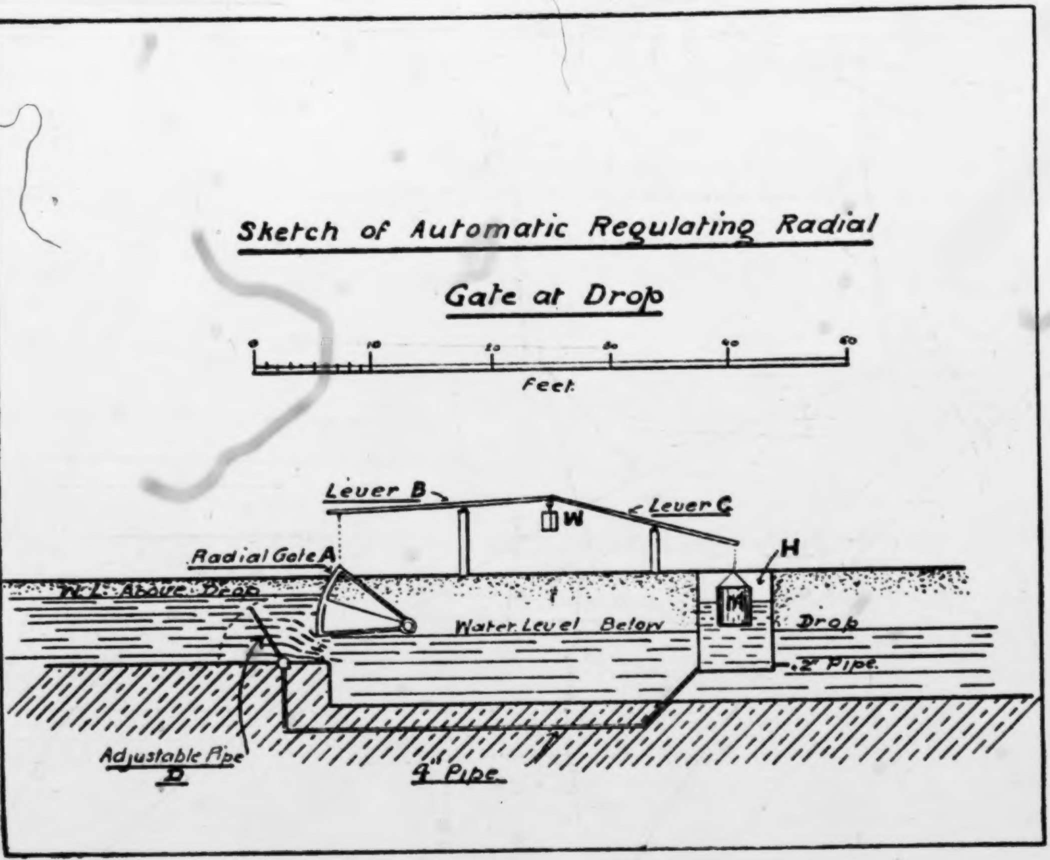

Sketch of Automatic Regulating Radial Gate at Drop
0
10
20
30
40
50
Feet
Lever B
W
Lever C
H
Radial Gate A
W.L. Above Drop
M
Water Level Below Drop
2" Pipe
Adjustable Pipe D
4" Pipe

Fig. 42.

When the irrigable flat is reached, the main canals run along the contours, and the distributaries down the slopes. Many drops are necessary on the latter, and the minors usually take off above the drops. Wood was very largely used, but concrete structures are now being built. The radial gate is very generally used in both districts. It is often counterbalanced, and its working is then very simple. At many of the drops on the Turlock system, the radial balanced-gate has been ingeniously adapted to give automatically a constant head above the drop. Such an arrangement is needed on these canals because, as we shall see later, the irrigating stream applied to the fields is often as

Radial Gates.

great as 12 cusecs, and the sudden shutting down of one or more of such streams would endanger the distributary. The device is very simple, and is illustrated in fig. 42. The radial gate (*a*) works across the main canal at the drop. It is counterbalanced by lever (*b*) and weight (*w*). The lever (*b*) is operated by another lever (*c*), to the other extremity of which is attached a weighted galvanized tank (*m*) of 3-foot diameter floating in another tank (*h*) which is built into the ground. This outer tank is filled by a 4-inch pipe from the water above the drop, and is emptied by a 2-inch pipe to the level below the drop. To the upper end of the 4-inch pipe is attached an adjustable length of pipe. This is set so that its mouth is slightly below the level to which it is desired to keep the water above the drop. If the water rises above this level, the 4-inch pipe fills the tank (*h*) quicker than the 2-inch pipe can drain it, and consequently the float (*m*) rises, and, by means of the levers (*c*) and (*b*), lifts the gate (*a*) and allows more water to pass the gate, thus lowering the level above the gate. When the level sinks below the mouth of the pipe (*d*), no water enters tank (*h*); the 2-inch pipe drains it; (*m*) sinks, (*a*) is then lowered, and the level above the drop rises again. The arrangement has been found to work very effectively. The radial type of gate lends itself to this automatic device because the friction is not so great or so uncertain as in other types of gate, the chief forces being the hydrostatic pressure and the weight of the gate, which are definite and easily calculated. The device is worth considering as an automatic escape on a big canal which is liable to catch much hill-side drainage.

Soils, Slopes, and Methods of Irrigation.

Two important characteristics of most of the soils in the whole San Joaquin Valley should first be noted. They are generally of a distinctly sandy nature, and very often have a hard-pan layer within 6 feet of the surface.

Very large areas, especially on the Turlock side, have a sandy appearance somewhat like our Cape Flats. To indicate the very sandy nature of the soil it should be mentioned that good clean sand is often taken direct from the beds of the canals for concrete.

The following is the physical analysis of this great type:—

Fine Gravel.	Coarse Sand.	Medium Sand.	Fine Sand.	Very Fine Sand.	Silt.	Clay.
1.0	12.7	19.9	41.1	15.9	7.4	1.7

Next to this sandy type in area is a finer sandy loam with the following physical analysis:—

Fine Gravel.	Coarse Sand.	Medium Sand.	Fine Sand.	Very Fine Sand.	Silt.	Clay.
1.7	11.9	11.0	26.8	10.7	32.7	5.3

The heavier loams and clays, such as were described in the "gumbo" soil of the Bellefourche scheme, are only found in very small areas and especially in the low lands close to the San Joaquin channel. Alkali is not very prevalent. Over the greater part of the light sandy soil it is less than .1 per cent., and is in dangerous quantities only in the heavy soils close to the river.

Hard-pan is commonly found under most of the area at a depth of about 1 to 4 feet. It is usually a hard-cemented calcareous layer several inches in thickness. It is remarkable that crops thrive as they do in the shallow soils overlying the impenetrable hard-pan. This hard-pan is common throughout the San Joaquin Valley, and a surface indication is the "hog-wallow" formation which consists of a series of hollows and squat rounded mounds only about 18 inches high and spaced with great regularity about every 30 feet over enormous areas.

The water-table, which was 30 feet to 40 feet deep in places, has risen to within 10 feet of the surface in less than ten years, and it has been found necessary to construct drains, especially in the low-lying parts near the San Joaquin River.

The general surface of the irrigable area slopes gently down towards the San Joaquin River (see contour plan). The valley is, to the eye, extraordinarily level, scarcely any hills disturbing the surface. The average slope of the lands towards the river is only about 6 feet per mile. With such a flat slope the basin-soakage system is largely used for irrigation, the basins being usually about 50 yards square. It should be mentioned that at first long basins were made parallel to the contours, thus forming terraces. The levelling of such basins was easy, as in the course of levelling the bordering walls were made. It was found, however, that the irrigation of such beds was not satisfactory, as the water had to be dropped from one basin to the next, and this system has now been abandoned. Wherever the slope is locally increased, as from natural ridges towards hollows, the method of surface-flow between borders is usually adopted, the beds being made about 60 feet wide and up to a quarter of a mile long. This method is adopted wherever possible, being naturally cheaper and easier.

A feature of the irrigation is that larger irrigating streams are applied to the fields than on any of the schemes previously described. Streams of 12 cusecs are commonly applied, and sometimes streams as great as 20 cusecs. This practice necessitates very large minors and large gates leading to each bed. Nearly all the beds are provided with large wooden gates. As a rule, a block-gate crosses the minor, and the field-gates are placed on opposite sides of the stream. The field-gates are mostly of wood, and the opening is usually about 6 feet wide and is closed by two 3-foot gates alongside each other. The sides of the cutting through the furrow-bank are retained by wood, and a wooden floor usually extends through the bank about 6 feet beyond the gates.

Crops.

In 1913 about 48,000 acres were irrigated in the Modesto district, and 85,000 acres in the Turlock district, or a total of 133,000 acres out of 225,000 acres included in the districts. Lucerne is the great crop, and covers about 75 per cent. of the area. Orchards and vines cover over 10 per cent. Cereals and vegetables occupy the rest. Cereals do well without irrigation in the rolling country at the foot of the mountains, and this partly accounts for the small area devoted to them under irrigation, but in California it is more fully realized that for the best results more profitable crops than cereals must be grown under irrigation. Lucerne gives four to five crops annually with a total yield of about 5 tons per acre, which sells at about $7 to $10 per ton in the stack, and at $10 to $15 baled. Much of the lucerne is, however, fed to cattle, and a large dairy industry depends on it.

Settlement and Cost.

The history and organization of this scheme is interesting, as the conditions are somewhat similar to those which are likely to be met with in co-operative work without Government assistance in South Africa. Unlike most of the schemes we have previously considered, the land to be irrigated was at the outset in private ownership, usually in very large areas, and was cultivated with cereals without irrigation. The first efforts towards forming an irrigation district were made in 1887, shortly after the Wright Law was passed by the California State, which provided for the constitution of irrigation districts. Many of the larger landowners were opposed to the scheme, as they were satisfied with the returns from cereals and feared the added expense of irrigation. So bitter was their opposition that they formed an "Anti-Irrigation League" and held up the scheme for thirteen years. Their resistance led to expensive litigation, and when the board of supervisors was elected they contrived to get a majority on the board who refused to levy the necessary taxes to raise funds for construction.

The Wright Law was amended by the Irrigation Act of 1897, which provided means of forcing a resisting minority into a co-operative scheme in a manner similar to the South African Irrigation Acts of 1906 and 1912. A majority of the owners under the proposed scheme, whose property valuation is also a majority, is sufficient for the preliminary formation, which has to be ratified later by a two-thirds majority. The whole area is then divided into five divisions roughly equal in size. Each division subsequently elects a representative as a member of a board of five supervisors, each owner having one vote irrespective of the area he owns. To raise funds for construction a majority representing a majority of the assessed values is necessary.

Recently a State Board has been constituted, consisting of the Attorney-General, the Superintendent of Banks, and the State Engineer, who must approve of the scheme before funds are raised. This is a wholesome check on wild-cat schemes. Funds are raised by issuing bonds on the market, the State providing that none be sold below par. This proviso is sometimes overcome by paying contractors in bonds, with an understanding that their value is below par. The bonds bear 5 per cent. interest and must be paid off within thirty years, commencing with the twenty-first year. In order to meet these capital payments as well as annual maintenance charges a uniform tax is levied on the assessed value of all land in the district. Even town lots are assessed, and usually at a much higher rate than the country lots. Thus, in the Modesto district, of the total assessment of seven million dollars the city property is assessed at one and a half million dollars. The assessment is made annually, and in making it the quality of soil and the position as to towns or stations are taken into account. In 1913 the following were average assessed values:—For outlying country areas $40 per acre, for areas closer to the towns $90, and for town areas about $1000 per acre. It will thus be seen that the towns, which owe their existence to the irrigation scheme, contribute largely to the cost. In fact the irrigation tax on town property is actually equal to all the other taxes, such as water, streets, schools, etc., put together. As the number of property owners is greater in the towns, the latter practically control the voting of funds, though not the election of the five supervisors, as the towns do not lie in each of the five divisions.

In the Modesto district the tax for 1912 was 2½ per cent. of the assessed values, and in 1913 3¾ per cent. (the increase being due to betterments carried out). In the Turlock district the corresponding figures were 2.4 per cent. and 3.55 per cent. The average assessment of the irrigable lands is about $60 per acre, and 3 per cent. on this gives $1.8 per assessed acre. About half of this is for capital charges, one-quarter for betterments, and one-quarter for maintenance. Between the twentieth and thirtieth years the bonds have to be paid off, and only maintenance and betterment charges will be made thereafter.

The charge on the assessed value of areas has had the effect of breaking up the large holdings. There is no limit as in the Carey Act to the area which an individual can hold, but the tax on the whole irrigable area forces the owner either to work it or to sub-divide and sell it. Whereas several owners held individual tracts of from 1000 to 2000 acres before the scheme was started, now not more than five or six in the Modesto district own more than 640 acres. In the Turlock district one or two hold individually over 2000 acres, and not more than twenty own over 640 acres. I have no actual figures of cost, but the cost up to date of the Modesto scheme is approximately $20 per irrigable acre, and of the Turlock scheme approximately $10.

Irrigation was commenced in 1903, and in 1913 about 60 per cent. of the total irrigable area was actually irrigated.

Distribution of Water and Duty.

All distribution is by rotation in both districts, this system being essential where such large irrigating streams are used. At the beginning of the season each irrigator declares the area he is going to irrigate, and the rotation is then worked out. The rotation is by turns, proceeding down each minor from top to bottom, and each man's turn comes round once in three weeks or a month. On the Modesto side the stream supplied is between 15 and 20 cusecs, and is run for a period calculated at the rate of 20 minutes per acre. This allows an application of about 5 inches to 6 inches to the fields.

On the Turlock side, where the soil is more sandy, the maximum rate is a 12-cusec stream for one hour, which gives a 12-inch application. As soon as each man has finished his whole area he must notify the next user to be ready. If a turn falls at an inconvenient time, e.g. at cutting of lucerne, an exchange can be mutually arranged. As the storage provided is too small the flow is insufficient towards the end of the season, and the number of irrigating streams is cut down, each keeping the same uniform strength, and those who suffer at the end of the season get the first turn at the beginning of the next season.

The above is the system for lucerne, which covers three-quarters of the area. For vegetables a smaller stream is supplied, and the rotation period is shorter.

No definite figures exist for duty, but it is estimated that the annual application is 4 feet, measured at the weir, and 3 feet measured at the fields. It should be noted, however, that the river-flow and the storage provided are insufficient for all needs towards the end of the season, and larger volumes would probably be used if the supply of water were greater.

CHAPTER XII

THE FRESNO SCHEMES
AND
THE REDLANDS SCHEME

FRESNO SCHEMES

Modesto to Fresno.

FROM the Modesto-Turlock scheme to Fresno, about 70 miles, the railway travels through the great basin and parallel to its axis and to the Sierra Nevada Range, crossing the Merced and San Joaquin Rivers and many sandy creeks. The country is very similar to that described at Modesto. Cereals grown without irrigation cover a considerable area and large areas are not cultivated, the "hog-wallow" formation being conspicuous over the enormous plain. On the way irrigation is practised on a large scale close to the foothills, among other large schemes being the Crocker-Huffman scheme from the Merced River, but the most remarkable development is the irrigation by pumping from underground supplies. Numerous electric lines traverse the great plain, deriving power from the streams coming down from the Sierra Nevadas. At intervals along the transmission lines transformers are seen on the poles, and immediately below each is a pump over a well serving a fine area of levelled and cultivated land in pleasing contrast to the surrounding undeveloped land. On the left bank of the San Joaquin River a large canal takes out just where the river makes a sharp bend after joining the Fresno Slough from Tulare Lake. This furrow, constructed by a company which owns large areas of land, runs for 70 miles down the left side of the river, and commands 340,000 acres, of which only one-third is irrigated and a large part is simply flooded pasturage.

Water Supply.

The Fresno schemes derive their water from the King's River. From this river over 600,000 acres are at present irrigated. The water is diverted on both sides of the river by numerous furrows, but the Fresno schemes lie entirely on the right bank and irrigate about 360,000 acres between the King's River and the San Joaquin River.

The King's River derives its water from the exceedingly high peaks of the Sierra Nevadas, and has a drainage area of about

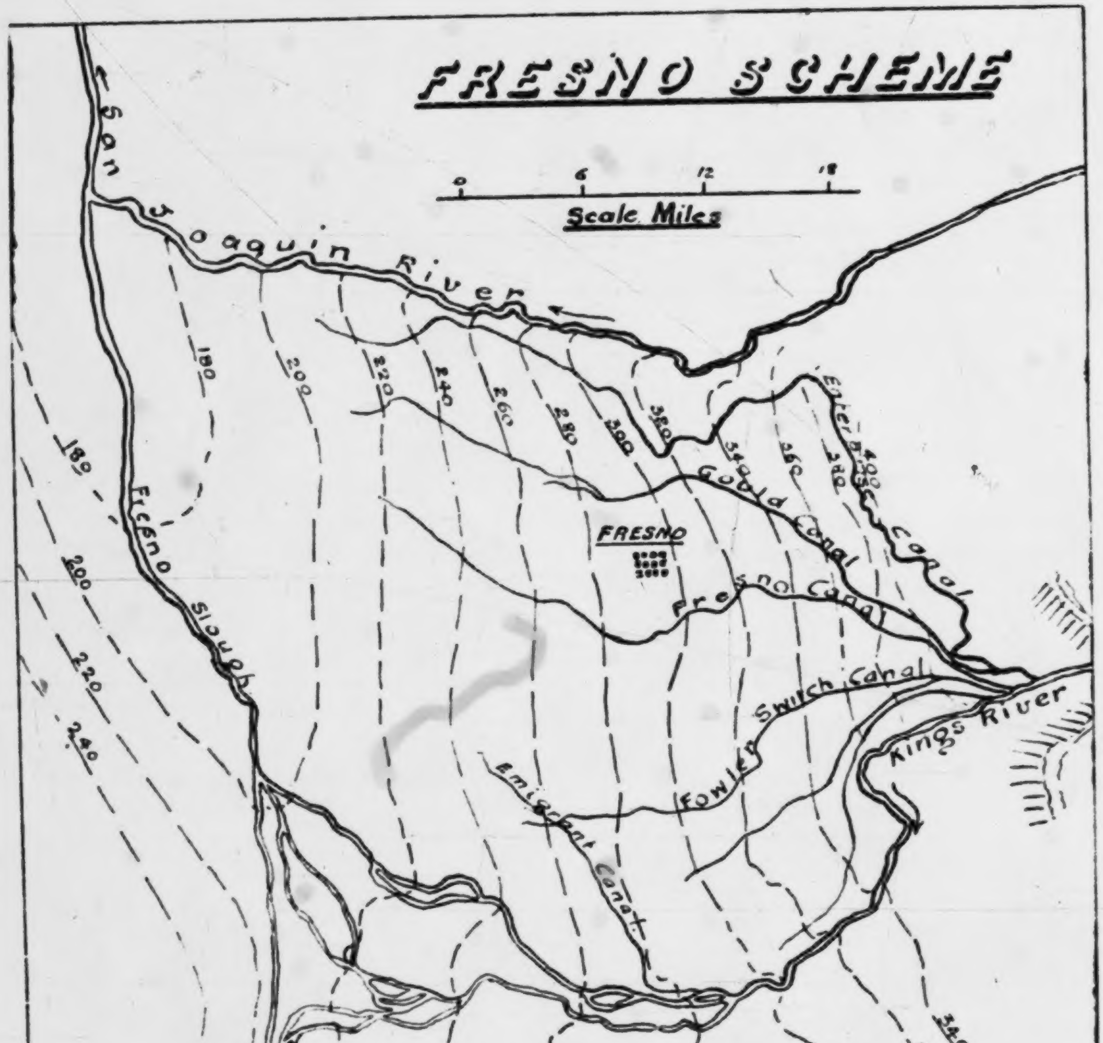

FRESNO SCHEME
0
6
12
18
Scale Miles
San Joaquin River
Fresno Slough
FRESNO
Gould Canal
Fresno Canal
Enterprise Canal
Fowler Swich Canal
Emigrant Canal
Kings River
TULARE LAKE
T.N.
180
200
220
240
260
280
300
320
340
360
380
400

Fig. 43.

1750 square miles above the highest canals. Its mean monthly discharge for thirteen years is as follows: —

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Cusecs ...	1175	1133	2246	3889	7714	8207	3715	1145	436	471	509	535

The yearly mean is 2598 cusecs, the maximum flood 44,000, and the minimum flow 130 cusecs. From this it will be seen that the supply is not nearly enough for the 600,000 acres under existing schemes, and some of these with inferior water-rights get water only in the early part of summer. No storage is provided, but continual irrigation has so raised the water-table that now less irrigation is necessary than formerly, and an enormous number of pumps utilize the underground supply.

Rainfall and Soil.

The rainfall is similar to that at Modesto, though the total annual fall is only 11¼ inches. June, July, and August are practically rainless months. The soil, also, is similar to that at Modesto, being generally of a sandy nature, and very often overlying a hard-pan layer at no great depth.

Works.

The numerous canals call for no special remarks from an engineering point of view. The river-channel is very shallow, and the water is easily turned out by low simple weirs, and the canals run in easy excavation—at first along the contours and then down the gentle slope, which is about 6 feet per mile towards the axis of the great basin.

Crops.

Fresno is the heart of the raisin and wine industries of California. It is possible to motor for a day through miles of unending vineyards. About 100,000 acres are covered with vineyards, mostly for raisins. The chief varieties of raisin-grapes are the Thompson Seedless and the Muscat. The dry, rainless summers favour the production of raisins, and stacks of trays with drying grapes are seen over the whole country. It is claimed that 1 acre will give 1 ton of raisins, which sells at $70, and the whole cost of cultivation, irrigation, picking, packing, etc., amounts to $30.

The wine output is over six million gallons annually. Enormous wineries are dotted over the district, and train-loads with open trucks full of grapes are often to be seen. The price paid for the grapes in trucks is about $10 per ton, and the yield is about 4 tons to the acre. Table grapes are also grown in large quantities and sent away packed in sawdust. Malaga, Emperor, and Flame Tokay are the chief varieties—Emperor being the best for packing. The best table grapes are, however, grown in the foothills above the big irrigation schemes. As a rule very little water is required by old vineyards, and about two waterings suffice for new vineyards.

Fruit trees are also largely grown, and dried and canned apricots, figs, peaches, and prunes form a considerable industry. Often, on account of the hard-pan formation, holes have to be blasted through the cement-hard layer to enable the roots to penetrate the soil deeply. Lucerne is also grown extensively for fodder, but usually in smaller beds than at Modesto. In several large areas it is obvious that the lucerne is suffering from seepage and alkali due to the rise of water-level.

Management and Cost.

The Fresno irrigation system is one of the oldest of the large schemes in California, having been constructed in the early seventies. Practically all the canals are now under the control of one company—the Fresno Canal and Irrigation Company. The three large canals—the Enterprise, the Fresno, and the Gould—have the oldest and best water-rights and a total capacity of over 1000 cusecs. They therefore absorb all the later summer flow, and the other canals get water only in early summer.

The Fresno Canal and Irrigation Company owns the canals. It is a private company and the actual irrigators have very little say in the management. Those who wish to irrigate lands commanded by the canals have bought from the company water-rights at $5 to $10 per acre, and are entitled to water at the rate of 1 cusec per 160 acres while the canal is running at the maximum flow to which it is entitled. All who have bought rights have, in addition, to pay to the company an annual water-rate of from 62½ to 75 cents per acre for the whole area under water-right, whether they use the water or not. The company constructed only the main canals, the irrigators constructing and maintaining the minors and arranging their own methods of distribution.

The lower irrigators on the minors often do not get as much as the upper owners, and a system of rotation is now under consideration which will allow a 5-inch watering while the canals are full, but when the supply falls a 2½-inch watering in eighteen-day periods. Details of the actual use of water are lacking, and the whole management being under a private company, details of cost and duty are naturally not available.

South of Fresno.

From the Fresno scheme southwards to the end of the great San Joaquin basin near Bakersfield the central part of the valley presents on the whole a very barren appearance, and the hog-wallow formation is noticeable. The greatest development is close up to the Sierra Nevada foothills, where oranges are grown in great quantities and very successfully, especially between Exeter and Terra Bella.

Shortly after Bakersfield (the famous oil centre) we leave the great fertile basin, climb up a steep slope, and enter the desert region on the way to Los Angeles and Redlands.

Los Angeles Aqueduct.

Mention should be made of the famous Los Angeles Aqueduct, now nearing completion, which is to carry 400 cusecs across this desert (some 230 miles) to the City of Los Angeles from Owens River above Owens Lake. For nearly 100 miles the water is carried in a closed concrete conduit, and for most of the remaining distance in concrete-lined channels, syphons, or aqueducts. This gigantic work is to cost over twenty million dollars.

THE REDLANDS SCHEME

This is the first big scheme on the Santa Ana River after it emerges from its canyon in the mountains. It is remarkable—as are most of the schemes on the Santa Ana River—for the great pains taken to prevent undue waste of water in its passage from the river to the fields.

Water Supply.

Above the point of diversion of the Santa Ana canal the drainage area is only 182 square miles. On one of the tributaries in this area is situated the famous Bear Valley arched-dam which has recently been enlarged to a capacity of 65,000 acre-feet, which is considerably above the mean average run-off. At the Santa Ana canal-diversion the run-off is about 57,000 acre-feet. The storage dam naturally interferes with the run-off figures at the above point, but the following figures are given as an average of twelve years:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Cusecs ...	60	98	169	147	96	69	59	52	48	46	48	38

Mean annual flow 78 cusecs. The maximum observed flood is 4900 cusecs, and the minimum flow 17 cusecs.

The source of the river is in the heart of the San Bernardino Range, which is a well-timbered granite formation, with peaks 10,000 to 12,000 feet high and therefore snow-covered.

The average annual rainfall at Redlands is 13 inches, by far the larger portion falling in winter, the months of June, July, and August being practically rainless.

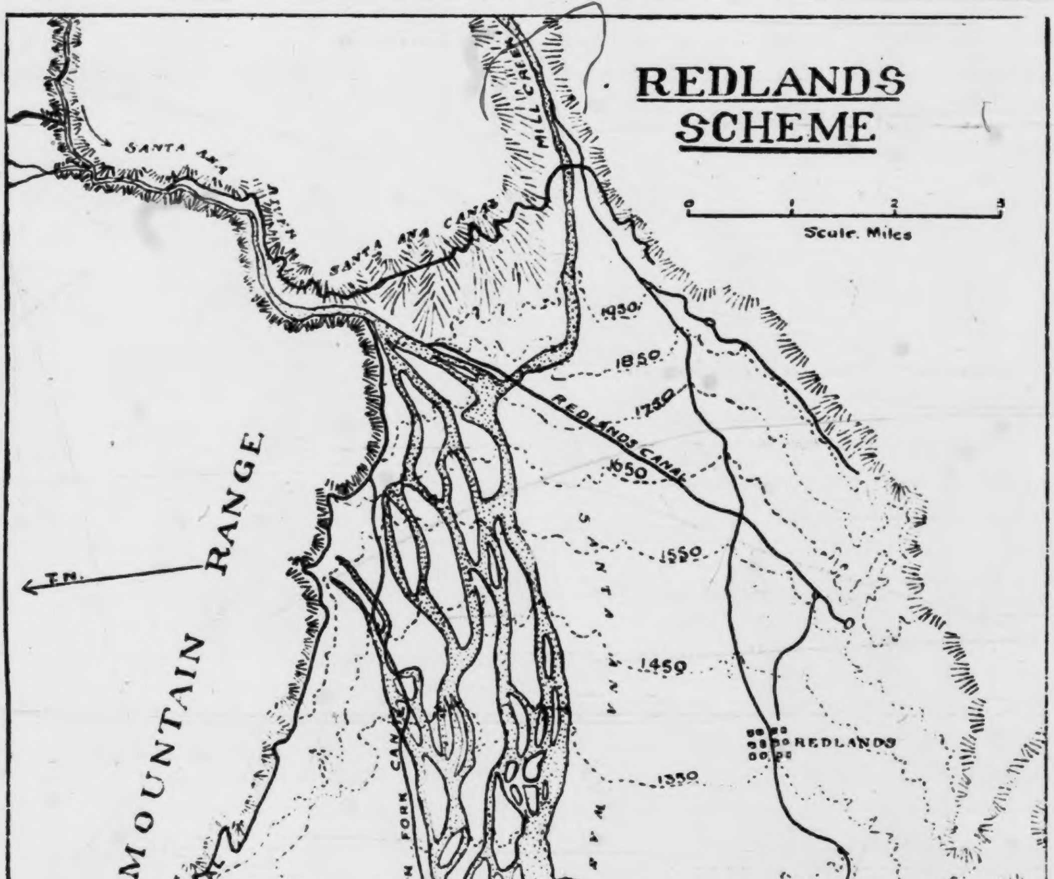

REDLANDS SCHEME
0
1
2
3
Scale, Miles
SANTA ANA RIVER
SANTA ANA CANAL
MILL CREEK
1950
1850
1750
REDLANDS CANAL
1650
1550
1450
1350
1250
1150
1050
SANTA ANA WASH
HIGH MOUNTAIN RANGE
T.N.
OLD NORTH FORK CANAL
HIGHLANDS CANAL
REDLANDS
SAN BERNARDINO

Fig. 44.

The temperature ranges from 112° F. to 24° F., but is seldom below freezing point and not often above 100° F. The mean annual temperature is 63° F.

After emerging from the canyon above Redlands the river spreads out over a sandy bed in the Santa Ana Wash. The irrigated lands under this scheme lie on each side of the wash at an elevation of from 1100 to 1600 feet, and are about 3 miles wide. The lower and flatter lands nearer the river are very sandy, but the steeper red soils nearer the hills are heavier. The greater part of the area is given to citrus cultivation. Most of the water is controlled by the Bear Valley Mutual Water Co., which supplies water to 15,000 acres with a duty of 1 cusec to 250 acres. Shares are bought from the Mutual Water Company, which entitle the holders to water at the above duty-rate. Thus a farmer with 25 acres would buy a share, which entitles him to $\frac{1}{10}$ cusec continuous flow. As a matter of fact the water is distributed in monthly rotations with bigger streams. The 25-acre holder would get, say, a $1\frac{1}{4}$ cusec stream for two days a month instead of a continuous flow of $\frac{1}{10}$ cusec for thirty days.

Orchard Irrigation.

To come out with the high duty of 250 acres per cusec on sandy soil very economical methods of distributing the water must be practised, and it is proposed to describe some of the methods adopted here and in other parts of the Santa Ana Valley. It is very rarely that the water, after leaving the river, is seen touching bare soil, except in the orchards where actually irrigating the soil. The open canals are concrete-lined, and all the distributaries and minors, even the smallest, are either pipes or open furrows lined with masonry or concrete. The slope of the ground between Redlands and the Wash is about 70 to 100 feet per mile parallel to the river, and in the sloping ground between Redlands and the hills it is much steeper. The furrow method of irrigating the orchards is the most general. Orange trees are planted 20 to 25 feet apart. Usually two irrigating furrows run down each side of a row of trees, making four furrows between each row. The trees are generally planted in such a way that the furrows can be run at a proper slope, not so steep as to scour the ground. The length of these furrows depends on the size of field, but on large farms is usually over 100 yards, 200 yards being not an uncommon length where the soil is not too sandy. In the flatter lands each will carry a stream up to $\frac{1}{10}$ cusec, but in the steeper and heavier soils a much smaller stream is used. The furrows are made by special shears attached to harrows. Immediately after irrigating they are harrowed over to

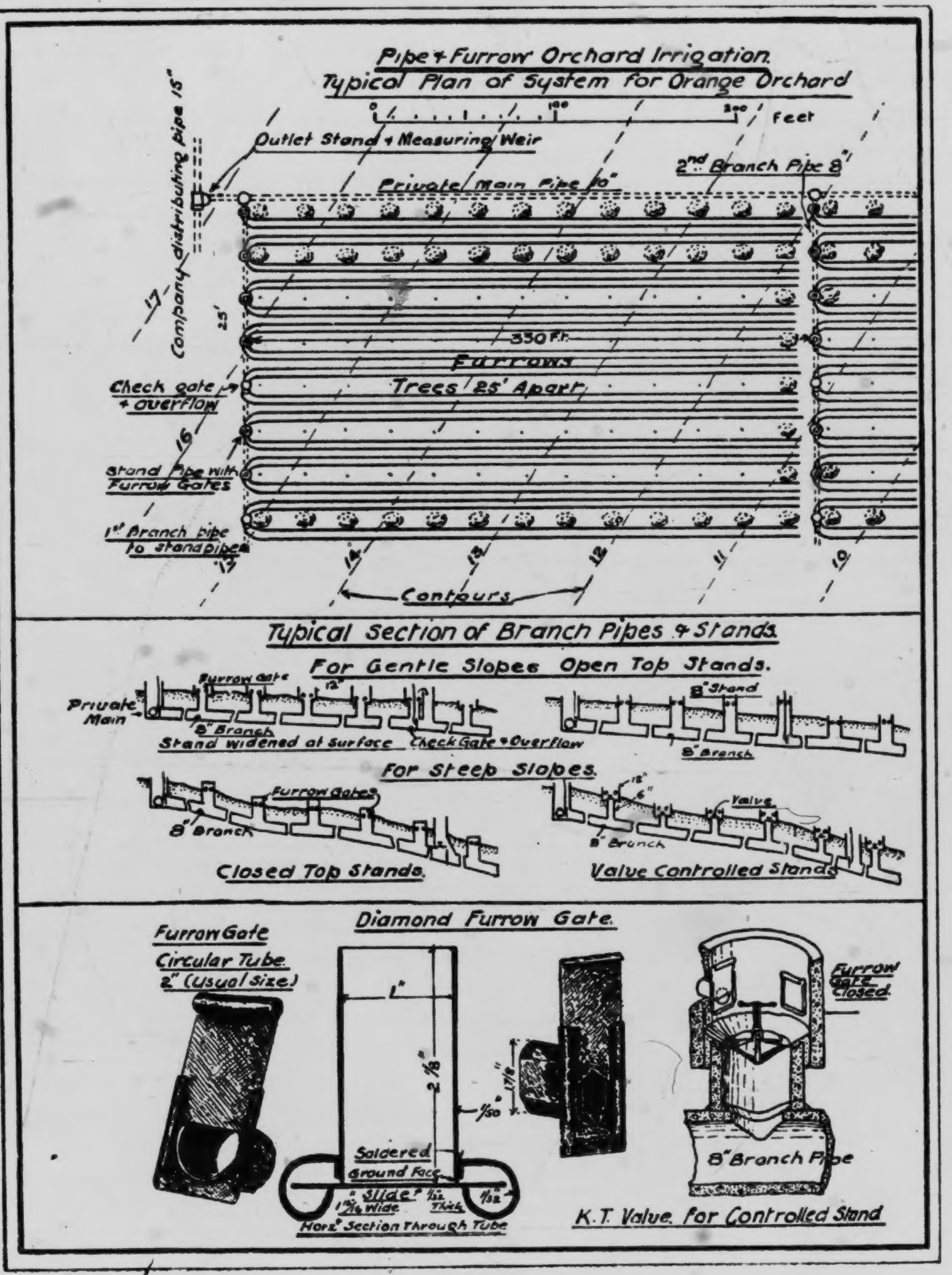
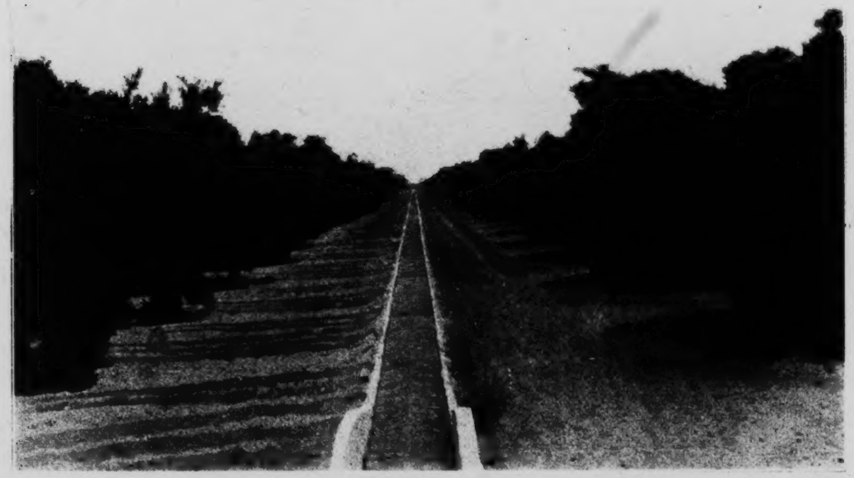
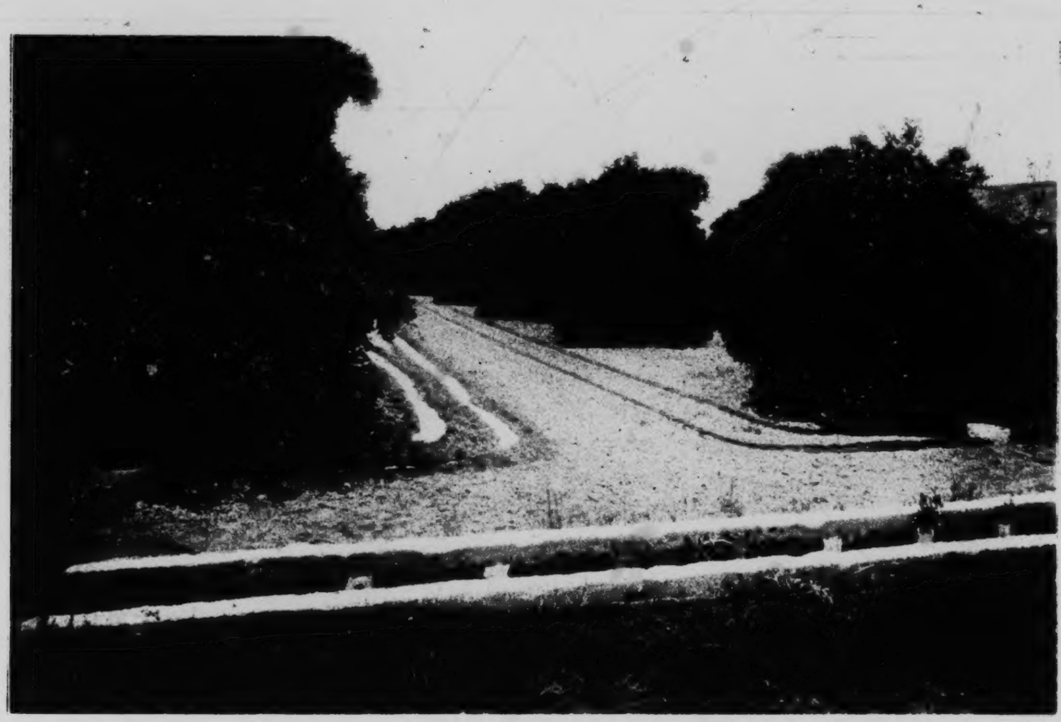

Pipe + Furrow Orchard Irrigation.
Typical Plan of System for Orange Orchard
0
100
200
Feet
Outlet Stand + Measuring Weir
Company distributing pipe 15"
2nd Branch Pipe 8"
Private Main Pipe 10"
25'
330 Ft.
Furrows
Trees 25' Apart
Check gate + overflow
Stand Pipe with Furrow Gates
1st Branch pipe to standpipes
17
16
15
14
13
12
11
10
Contours
Typical Section of Branch Pipes + Stands.
For Gentle Slopes Open Top Stands.
Private Main
Furrow Gate
12"
8" Branch
Stand widened at Surface
Check Gate + Overflow
8" Stand
8" Branch
For Steep Slopes.
Furrow Gates
8" Branch
Closed Top Stands.
12"
6"
Valve
8" Branch
Valve Controlled Stands
Diamond Furrow Gate.
Furrow Gate
Circular Tube.
2" (Usual size)
1"
2 7/8"
1/50
1 7/8"
Soldered
Ground Face
Slide
1 1/16 Wide
1/32 Thick
1/32
Horz. Section Through Tube
Furrow Gate Closed
8" Branch Pipe
K.T. Valve. For Controlled Stand

Fig. 45.

South California—Orchard Irrigation.



(*a*) Open Masonry Furrow Distributary, supplying irrigating furrows through small furrow-gates in sides. Irrigating on left; on right, harrowed after irrigation.



(*b*) Old Open Furrow Distributory abandoned and replaced by underground pipe, with a standpipe at the head of each row of trees.

Plate 14.

South California—Orchard Irrigation.

(c) Where trees are further apart (Olives and Walnuts), an additional stand-pipe is placed between the rows.

prevent loss by evaporation, and new furrows are made before each irrigation.

Small Furrow Gates.

Each of these furrows is supplied with water through a small gate in the side of the open-masonry furrows or in the sides of the vertical stand-pipes. Two types of small gates are shown at the bottom left corner of fig. 45. They are made of thin galvanized sheet-metal. The tube, which is built into the concrete, is either round (K.T. type) or elongated (diamond type). The inner end passes through a vertical plate and is connected with it by crimping (K.T.) or soldering (diamond). The sides of the vertical plate are bent round (see section) so as to form roll-springs for pressing the sliding gate against the end of the tube, which is ground to a true face. The gate is held by the springs in any position, and when closed is water-tight. Common sizes are 2 and 3 square inches. The cost of a 2½-inch diameter K.T. gate with 3-inch tube is 6 cents (3d.), and the cost of the diamond gate shown is 8 cents.

Masonry Furrows.

Two methods of getting the water from the mains to the small irrigating furrows are practised—the open-furrow method and the pipe method. The latter method is now the commonest, and is gradually supplanting the former (see photos A and B, plate 14). The open furrows are made in various ways. Wooden troughs are still seen in square or V-shaped sections. Galvanized iron is also used in V-shaped sections, but the commonest open furrows are made of brick coated with cement, of cobbles in cement, or of concrete. They vary in width from 4 inches up to 15 inches. A typical large open furrow is shown in photo A. The water is headed up at frequent intervals (as in photo) to supply the small furrow-gates in each length, or the furrow-gates are placed at a level below the floor and fed by slots running across the bottom.

Pipe Distribution.

The pipe method of distribution has many advantages over the open-furrow method, the chief being that cultivation and carting of crops can be done freely without interference from the pipes, whereas masonry furrows obstruct these operations. The pipe method is illustrated on plate 14 and fig. 45. From the company's distributing pipe the owner's private main runs along the upper edge of the field parallel to the irrigating furrows. In the plan the furrows have been made 330 feet long, and at the head of each set of furrows a branch pipe runs off from the private main and supplies a stand-pipe at the head of each row of trees. The stand-pipe has four holes, each with a small furrow-gate through which each of the irrigating furrows gets its supply. Typical sections of the arrangement of these stand-pipes are shown on fig. 45. The two methods in the upper sections are suitable for comparatively level ground with a gentle slope (as at Redlands). In the first method the vertical stand-pipes are enlarged at the surface and a check-gate and overflow are provided in the branch pipe at regular intervals where the level is dropped 1 or 2 feet. The third and fourth methods are suitable for uneven or steep ground. In the third, the tops of the vertical pipes are closed and bye-pass valves divide the branch into sections. In the fourth method a control-valve is provided in each stand-pipe before the water reaches the furrow-gates. A section of this type is shown in the right corner at the bottom of fig. 45. In this case the check-gate dividing the branch into sections has to face up-stream. The K.T. control-valve for an 8-inch pipe (5-inch opening) weighs 5 lb. and costs 75 cents. The Kellar-Thomason Co., of Los Angeles, make a special feature of this system.

The distributing or main pipes are of glazed tile, or more commonly of cement, in 2-foot or 3-foot lengths. Stand-pipes are attached to them by knocking out a hole to fit the bottom of the stand-pipe and cementing up the joint.

Cost. I was not able to get figures of the cost of the scheme, but was informed that, when water is sold to non-stockholders, a charge is made at the rate of about \$12½ per acre-foot, so that it would cost about \$3 per acre for each 3-inch watering.

Oranges. Oranges are by far the largest product of the irrigated land. Washington Navel and Late Valencias are the chief varieties grown. They sell at \$1 to \$2 per box, which contains 70-200, according to size. A rough and ready rule gives a return per tree of one box for every year of age. Land, with groves in full bearing, sells at \$1500 to \$2500 per acre.

Co-operation. Here, and in South California generally, co-operation among orange growers has reached a higher state of development and success than in any other part of America. Co-operative enterprise had at the outset to fight its way against many obstacles—first, the traditional independence of individual farmers, then the opposition of local traders, lack of business training of farmers, suspicion of the integrity and efficiency of officers, legal defects in rules of organizations, etc. These have been gradually fought down, and now co-operation is established on a firm and business-like basis.

The individual associations are numerous and not too big. They are grouped, as far as possible, according to similarity of soil and product. A central Californian Fruit Growers' Association handles over 60 per cent. of the citrus crop of California. As a rule each association makes rigid contracts with the growers for three or five years for the whole crop, with penalties for sale outside the association and for breach of rules for picking, grading, packing, etc. Often all the latter processes are done by trained gangs organized by the association, who deal with all the orchards, the fruit being pooled and sold under the association brand. The association also deals with the purchase of fertilizers, boxes, nails, wrapping paper, etc.; and with the provision of spray and fumigating outfits, frost protectors, etc. Each association gets daily bulletins of the markets and sells to wholesale dealers in the most favourable markets. There are fourteen co-operative packing-houses in Redlands.

Irrigation below Redlands.

Although Redlands absorbs most of the visible flow of the river after emerging from the canyon, yet irrigation is practised extensively all along its lower course, the water lost by percolation being raised to the surface over and over again, either naturally by rocky reefs crossing the river or by pumping. The number of pumps working in wells in the sand and gravel is extraordinary. Close to Redlands I saw one being sunk about 300 feet. The diameter of the hole was about 15 inches, and it was lined with pipes which were pierced by a special tool at the depth at which the water was found. A supply as great as 2 cusecs is obtained from the hole. Similar wells are numerous all down the Santa Ana River and in the neighbourhood of Los Angeles, though it should be noted that not all are successful, as often the underground supply is pumped out and diminishes in a short time. Most of the small schemes distribute the precious water in the same economical way as described above. Oranges are usually grown in this area, but large orchards of olives and walnuts are also seen—the latter spaced in rows further apart than the oranges.

Between Redlands and Los Angeles, vineyards are numerous, and in one place I saw one continuous vineyard of about 4000 acres grown on white sandy soil without irrigation.

CHAPTER XIII

THE IMPERIAL VALLEY SCHEME

FROM Redlands to the Imperial Valley scheme on the Mexican border is some 200 miles, mostly through desert country. The conditions on this scheme, in many respects, resemble those of the Punjab schemes in India, and the soil, climate, and muddiness of the water are somewhat similar to those of the Zak and Fish Rivers in the north-west of the Cape Province of South Africa. The scheme is the largest in America, and presents many unique features. The irrigable lands lie mostly below sea-level, and the main canal and part of the lands lie over the border in Mexican territory. From the map on plate 15, the peculiar position of the irrigable lands can be seen. The Colorado River, in the last 75 miles of its length before ending in the Gulf of California, runs in a south-westerly direction through a delta along the edge of a huge depression of alluvial soil extending nearly 100 miles towards the north-west. This depression is almost entirely surrounded by high mountains, and its lowest point in the Salton Sea is actually 280 feet below sea-level. It is reasonable to suppose that the Gulf of California formerly extended over the whole of this area, but that the Colorado River, which, as we shall see, carries enormous quantities of silt, gradually pushed out a delta right across the gulf and chose its main course along the southern edge of the delta, leaving the enormous depression to the north to dry out and receive water only when the river breaks out in that direction in high flood.

The lowest point in the divide separating the slope towards the Gulf of California from the slope towards the Salton depression is in the neighbourhood of Volcano Lake, and about 30 feet above sea-level, and the area of the depression below this level is 1950 square miles. Of this area 1750 square miles, or over one million acres, lie below sea-level, and include the greater part of the area at present irrigated. As the mean annual discharge of the Colorado River is about 16½ million acre-feet, and the evaporation is about 6 feet in a year, it is obvious that if the river were to break through into the depression it would eventually drown out the whole area. This is a constant source of danger, and millions of dollars have already been spent to keep the river out of the depression, and probably millions will still have to be spent to render the depression safe from inundation. In November, 1905, the river broke through and threatened the whole valley with disaster, the water filling up the depression to a maximum depth of 76 feet in less than two years. The river was then successfully turned again towards the Gulf of California, and the water has fallen to a depth of about 50 feet and now covers an area of about 300 square miles.

Water Supply.

The Colorado River drains a total area of about 265,000 square miles, the furthest waters coming from the Rocky Mountains near the Yellowstone Park in Wyoming (see inset map). The branches in the northern part of the drainage area derive their waters mostly from melting snows, and behave therefore in the regular manner of such rivers as the Shoshone or Yellowstone previously described, reaching their maximum discharge about the month of June and being fairly clear and free from silt. The branches in the southern part of the drainage area have quite a different character, and are more like our South African rivers. They are often dry and come down in enormous floods after heavy rainfall. These floods occur in all months of the year except May, June, and July, so that they rarely coincide with the maximum flow from the northern branches.

The average annual rainfall over the entire drainage area is about 13 inches.

The maximum annual run-off at Yuma is 25,900,000 acre-feet, and the minimum 7,960,000 acre-feet. The mean from 1902 to 1911 is 16,500,000 acre-feet.

The maximum discharge observed is 149,500 cusecs, and the minimum 2400 cusecs.

The mean monthly discharge from 1903 to 1912 is approximately as follows:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Cusecs...	8148	9515	16,192	22,127	41,007	71,721	44,768	20,562	14,009	12,112	8802	7304

Silt.

This enormous river differs from those previously described chiefly in the amount of silt carried in suspension. In the former schemes to the north the waters are comparatively clear, and little trouble is experienced from silt deposits. In the Colorado River, however, the water is usually coloured by reason of silt in suspension, and we have the difficult problems of silt clearance familiar to irrigators in the Punjab and South Africa. Careful observations of the proportion of silt have been made. Generally, the percentage of silt increases with the discharge and reaches its maximum in a flood from the southern drainage area. Thus, in 1900 the percentage by volume varied from .062 per cent. during the low-water period to .374 per cent. in June, and reached a maximum of 2.07 per cent. during autumn floods from Arizona.

Silt observations at Yuma from 1909 to 1912 showed that about 0.75 per cent. by weight of the whole flow in this period was silt, or, roughly, 8½ tons per acre-foot. Applying this result to the mean annual discharge, which is given above as 16½ million acre-feet, we see that the river brings down annually about 140 million tons of silt, enough, if it were all abstracted, to make about 125 square miles or 80,000 acres of dry alluvial soil 1 foot deep every year. This vast amount of silt will have to be seriously considered when reservoirs are constructed, whether for storage or control of the floods.

The rainfall over the irrigable area is only about 2½ inches, irregularly distributed over the area and throughout the year, though the main fall is in winter. With such a small rainfall, cultivation is quite impossible without irrigation.

Temperature.

This region is notorious as one of the hottest in America. Temperatures as high as 125° F. have been observed, and for eight months of the year maximum temperatures of over 100° may be expected. The climate is dry, however, and the sky is usually clear, so that the nights are often much cooler than the days. The temperature rarely falls below freezing point, and the minimum observed temperature is 22° F.

Vegetation.

Natural vegetation is very scanty except near the river, where it grows thickly within reach of the water, and some of the growths resemble those of South Africa. Perhaps the most abundant growth is the arrow weed (*Pluchea sericea*), which grows very densely in bushes 3 to 6 feet high. Each bush consists of a number of straight stems radiating from the ground, and the leaves are almond-shaped, about 4 inches long by 1 inch wide. The South African "tontelbosch" somewhat resembles it in appearance. The dry, straight stems are used extensively for thatch roofs and shelters from the sun. Willows also grow along the water edge, and young plants spring up thickly, as along our Orange River. Further back from the water edge thorn trees like our mimosa are very common, and the chief types are the mesquite (*Prosopis juliflora*) and screwbean (*Prosopis pubescens*) trees. The former bears big beans about 6 inches long, which are very pleasant and sweet to taste, and are greedily eaten by stock, and are ground for food by the Indians. When these trees are dead they look much like our kareedoorn trees, and, like these, are an excellent firewood. They give a poor shade, but many a camp is formed under them for slight shelter from the great heat, as under our karreedoorns in the north-west. The screwbean is a similar thorn tree with beans curved in a spiral with many turns. Some screwbeans were introduced into South Africa some years ago, and are now growing very successfully at Van Wijks Vlei. Other growths similar to ours are an ink-bush, which grows taller than our flat variety; a big-growing salt bush; and I saw a few wild tobacco trees exactly like ours. I also saw the latter on the Modesto-Turlock and Salt River schemes, and learnt that they are quite a recent growth in America.

Underground water has not been found at reasonable depth under the area, except in one or two spots, and consequently the domestic supply depends entirely on the water from the river, and the canals must be run throughout the year.

Outline of Scheme.

The intake is at Pilot Knob, just inside American territory. This knob is the only rocky bank to the river within many miles. The intake-gates have been built on the rock, and there is no weir across the river. For the first four miles, as shown roughly on the plan, a canal was excavated parallel to the river, and thereafter the natural Alamo Branch was used for forty miles by deepening it in the upper portions and strengthening its banks where liable to overflow in the middle and lower lengths. In this way the water was conveyed very cheaply through Mexican territory to within two miles of the boundary line. Here the first check across the channel is built to divert water to the main eastern canal, which, on reaching American soil, spreads out in a series of canals to irrigate the area east of the Alamo Branch. About a mile below this check, and still about a mile outside the American border, the canalized length of the Alamo Branch ends. A wooden regulating-weir is built across the Alamo, and the main western canal starts above it, surplus water passing the weir and running to waste through the Alamo to Salton Sea. The main western canal is divided after a short distance (at Sharp), some canals running down the central area between the New and Alamo Rivers, and a large main canal crossing the New River in the Encina flume to irrigate the lands west of New River.

Control of River.

The scheme appears to be one of the simplest imaginable, but its history shows what enormous difficulties have to be overcome, the chief of these being to prevent the Colorado River from breaking into the Salton depression. Several times since the commencement of the scheme the river has actually broken through, and, in spite of enormous expenditure already incurred in preventive measures, the problem is not yet completely solved, as is proved by the inroads of the river and the actual breaking of the levee near Volcano Lake in June of this year (1914).

The confinement of the river is by far the greatest engineering feature of the scheme, and it is proposed briefly to describe the methods adopted and the difficulties encountered. At the outset it should be mentioned that the difficulties were greatly increased by the fact that practically the whole of the delta and the main canal lie across the border in foreign territory (Mexican) and consequently all work done there was hampered by international complications. At the same time it must be confessed that mistakes and short-cuts in design, especially of the head-works, and failure to appreciate at the outset the magnitude of the danger, are largely responsible for almost disastrous results. It should be noted, too, that once irrigation was started and settlers had arrived, it was absolutely essential that water should be supplied continuously through the system, as there is no other supply of water for domestic purposes. This fact should be remembered in reading the history of the river-control, as it aggravated the difficulties.

The delta of the Colorado begins shortly below Yuma and forms roughly an equilateral triangle with each side about 60 miles in length. The international boundary forms roughly one side, and the most eastern channel of the Colorado runs close to the other side, and the third side rests against the mountains of the west.

Previous to 1900, when work was started on the scheme, the main channel had always been the most easterly branch. Only in high floods did the water leave this channel, and then it usually spread as a sheet over the delta, and only occasionally found its way through Alamo or New River into Salton Sea in small volumes. The numerous branches now existing did not extend as very definite channels up to the edge of the main channel, but were only hollow depressions thickly covered with vegetation. It is really remarkable that the main channel should have continued so long on the eastern edge of the delta when the much greater slope towards Salton Sea, which is more than 270 feet below sea-level, is considered. The longitudinal slope of the river along the main channel is only about 1¼ foot per mile, and, as the river builds up its banks and bed with the deposits of silt, it is natural to

Plate 15.

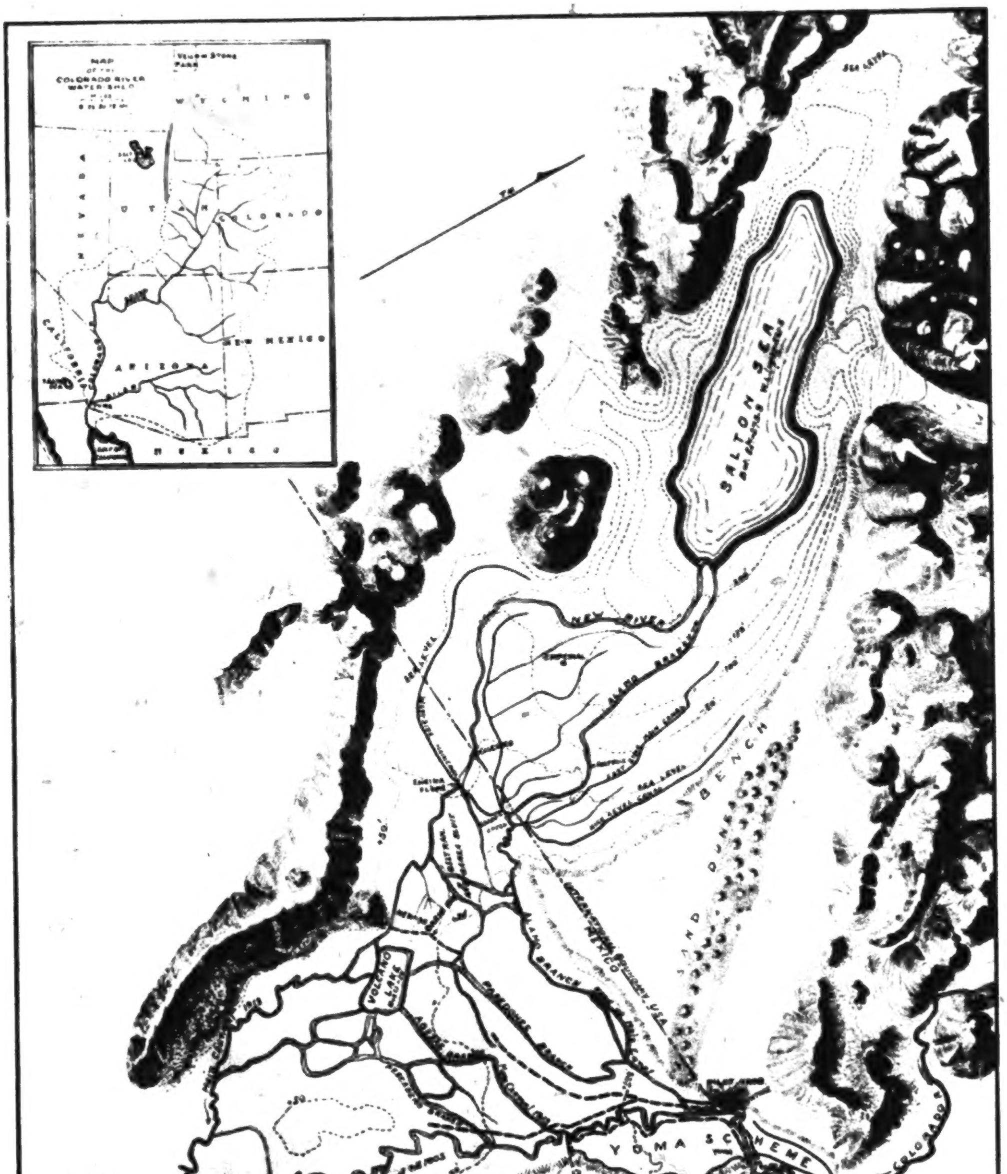
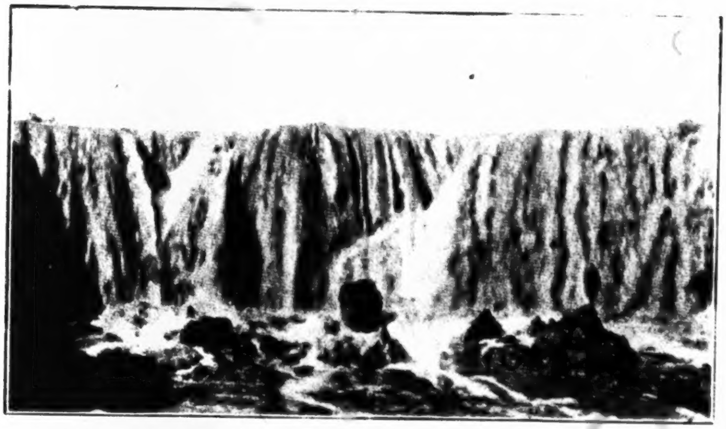

MAP OF THE COLORADO RIVER WATER SHED
YELLOW STONE PARK
WYOMING
NEVADA
UTAH
COLORADO
CALIFORNIA
ARIZONA
NEW MEXICO
MEXICO
SALTON SEA
NEW RIVER
BENCH
SAND DUNES
VOLCANO LAKE
COLORADO RIVER
YUMA SCHEME
COLORADO R.
LAGUNA WEIR
GILA RIVER
GULF OF CALIFORNIA
IMPERIAL VALLEY SCHEME.
REFERENCE
Canals.
Contours
Levees.
MILES

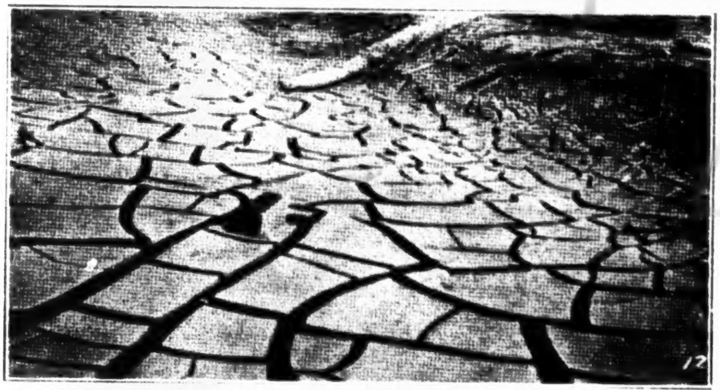
Fig. 46.

Plate 15.

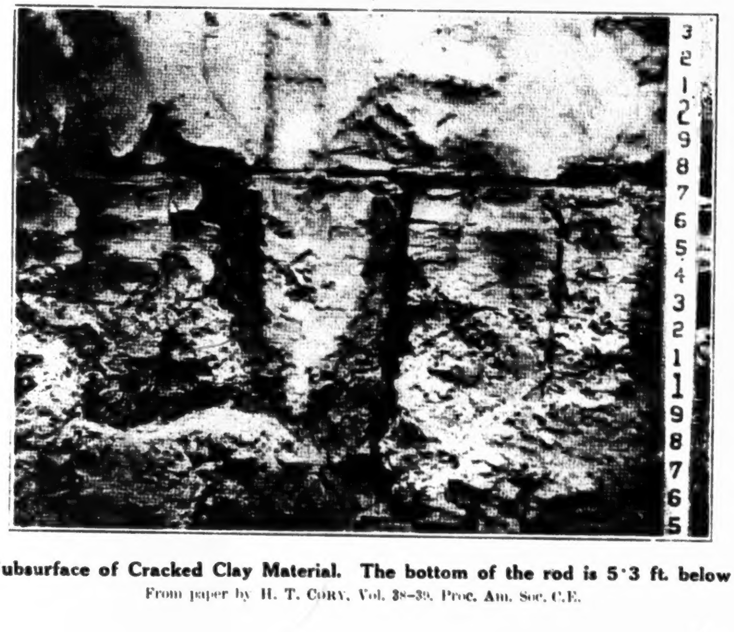
IMPERIAL VALLEY SCHEME.



(*a*) Sluiting in New River near Calexico. Maximum rate of recession, 1 ft. per minute. Drop 28 ft. June, 1906.



(*b*) Typical Surface of Cracked Clay Soil formed by silt deposit.



(c) Typical Subsurface of Cracked Clay Material. The bottom of the rod is 5·3 ft. below the surface.

From paper by H. T. CORY, Vol. 38–39, Proc. Am. Soc. C.E.

expect it eventually to seek the easier slope of about 4 feet per mile down towards Salton Sea, and this is the present tendency and the great danger. But at the time of construction, the main channel was still on the east, and no great danger appears to have been anticipated then.

The original head-gate was constructed in 1900 just inside the American border. It was a wooden structure and was built on the silt banks. Unfortunately, the sill was placed too high to get a sufficient supply during low water. Within two years water was supplied for irrigation, and settlement proceeded so rapidly that, although the area was a desert in 1900, by 1905 the population was over 12,000, all depending for even their drinking water on the canals. During the first few years after construction, it was found that the silt-deposit in the upper miles of the main canal was so great during the flood period that it was very difficult to clear away the vast quantities of silt fast enough to enable the low-water flow to pass in sufficient volume. After the summer floods of 1904 the silting had become so great in the first four miles of the canal that it was impossible to clean it out sufficiently to supply the settlers with water when the water-level in the river subsided.

At the end of the four miles, the canal bed was lower, and, being close to the river there, it was decided to make a temporary cut from the river to this point and to supply the canal through it instead of through the head-gate. This was done in September, 1904, and, as a result, the valley was supplied with water successfully that year. No regulating-gate was placed in the cut, as it was intended to close the cut as soon as the summer floods of 1905 rose high enough to pass enough through the upper original gate and the silted four miles. Unfortunately, the floods of 1905 came earlier than usual, and before the gap could be closed. The gap was rapidly widened and deepened, and, in spite of many attempts to close it, within a short time the whole flood of the Colorado was passing through the gap, leaving the main eastern channel high and dry. The water ran down the Alamo Branch, overflowing its banks and spreading over the flat country, most of it reaching New River through Beltran and Garza sluits and eventually falling into Salton Sea. Alamo Branch, however, always carried enough water to the weir near the boundary, and, consequently, the canals got sufficient water all the time. Nothing could be done to stop the gap during the summer flood of 1905, but, when the flood subsided in autumn, attempts were made to close the gap by means of piles and brush and soil dams. A sudden flood in November reaching 115,000 cusecs carried the work away and widened the gap to 600 feet.

Financial and other difficulties prevented the closing of the gap during the remainder of that low-water period, and the very big summer flood of 1906 also passed through the gap instead of the old eastern main channel. During this time, however, the following plan of closing the gap was being carried out. A huge wooden head-gate, 200 feet wide, was constructed alongside the gap with the intention of cutting a bye-pass through it so as to reduce the flow through the gap during closure. In October, 1906, after the summer flood had subsided, the wide gap was closed by dumping rock on fascine mattresses, so that all the water went through the new wooden gate, but this was very soon carried away and the whole flow soon ran through the new gap. This was closed in November by dumping rock, and a small flow was obtained through the old four miles of canal which had been partly cleaned out and provided with a new head-gate on the rock of Pilot Knob. The following month, however, the water cut through round the side of the dams closing the gap, and the whole flow again went towards Salton Sea. This gap was successfully closed in February, 1907, at a cost of one million dollars, by dumping rock very rapidly in two parallel lines from trestles, and thereafter water has always reached the valley through the gate at Pilot Knob, and no further breach into the Alamo River has occurred.

We thus see what serious results followed the apparently simple cutting from the river to the canal at four miles below the head-gate. For two years, 1905 and 1906, both with very heavy flood seasons, practically the whole flow of the river passed through the gap and most of it eventually reached Salton Sea by way of Beltran and Garza sluits and New River. The sluiting which resulted was extraordinary. Previous to the overflow, New River was an insignificant depression. The enormous flow running down the steep slope started a big sluit near the Salton Sea, and this crept back at an almost incredible rate past Imperial and finally for several miles beyond the boundary at Calexico. At the head of the advancing sluit the water fell some 30 feet over a width of about a quarter of a mile, the soil crumbling away and the fall retreating at a rate, at times, as great as 1 foot per minute (see photo A, plate 15). Fortunately, the gap was closed before the sluiting had cut back through Beltran and Garza sluits to the Alamo River. If this had happened, the Alamo River would have taken this course, and the whole Colorado River would have discharged into the Salton depression and submerged the lands. As it was, the Salton Sea was raised by 76 feet as the result of the two years' inflow. The closing of the gap cost over two million dollars, and up to the present the work has succeeded in preventing the flooding of the valley by way of the Alamo channel and in turning the river again down the old main channel on the east.

The other channels, such as the Paredones, Abejas, and Pescadero, discharged mostly into Volcano Lake, and from Volcano Lake flowed into the gulf through a channel close to the western mountains. It was possible, however, for summer flood waters, which overflow the ground traversed by these channels, to break through towards Salton Sea, especially from Volcano Lake, which is separated from New River by only a very low neck. To guard against this possibility, an extensive system of levees was designed with the purpose of confining the flow to the old main eastern channel. Levees have been built close to the old main channel and extending from the head-gate down-stream for nearly 40 miles. A curving levee was also built, as shown on the plan, to turn the water towards Volcano Lake in case of failure of the first line, and another levee was built north of Lake Volcano to prevent overflow to New River, which would cut the channel back to Volcano Lake. All the levees were constructed at enormous expenditure, but have not succeeded in making the valley secure from inundation. In 1910 the river broke through into the Abejas channel, and, in spite of extensive attempts to close the breach, the main flow has continued to be through the Abejas channel to Volcano Lake, and thence by the western foothill channel to the sea. the old main channel from the Abejas head to the sea remaining dry. The levee north of Volcano Lake has therefore to preserve the valley at present, but in June, 1914, during a flood of over 140,000 cusecs, this breached. During the same flood the levee near the old gap at the fourth mile of the canal was very nearly washed away, and the valley was again threatened with inundation by way of the Alamo channel.

It will be seen therefore that the Colorado is not yet under proper control, and enormous sums will have to be spent to subdue it and eliminate the danger of flooding out the irrigable area. It is probable that success will be achieved only when a very substantial levee is built (continuously from the head-works) close to the old main channel, and the banks of the low-water channel are lined with stone wherever the river is inclined to meander. This is the method adopted on the Yuma scheme with success, but the cost is very great, as the river constantly tends to shift its course, and, at flood times, pools against the banks are often scoured out to a depth of 30 feet or more.

Levee Construction. The method of constructing the levees is interesting, as the soil conditions are very similar to those encountered in building basins for irrigation along the Zak River. The soil consists of layers of sandy and very fine silt. The latter, on drying, crack very extensively (see photo C, plate 15). While wet, the silt expands and closes the cracks, but during the low-water periods the water retreats from the levees and the soil can then dry out sufficiently to cause cracks. The first flood, rising against the levee before the silt has time to swell and close the cracks, finds a way along a crack and begins bubbling out, often many yards below the levee, enlarges the crack, and, unless checked, causes a breach very rapidly. To prevent this it is now the common practice to excavate a trench at the up-stream toe, 6 feet wide on the bottom, which is carried below the dangerous cracked layers, usually to about 5 feet below the surface. The excavated material is replaced in the trench and the levee constructed thereon. The average height of the levees is 8 feet, top-width 10 feet, and side-slopes 1 on 3. The top and slopes are usually covered with 15 inches of gravel.

Another important problem is the location of the borrow-pits. It is generally recognized that to place them on the down-stream side is bad practice, as leakage is encouraged. They are usually placed on the up-stream or river side. Here there is a danger of the stream scouring a channel through the borrow-pits. To avoid this a berm is left of at least 40 feet width, and the borrow-pits are a series of holes separated from each other by undisturbed natural soil of the same width as the borrow-pits, usually about 30 yards. The tendency then is for these holes to silt up.

Head-Gate. The head-gate was at first a wooden structure built on the soil. This, as we have seen, was built with sill too high, and was replaced by a steel and concrete structure built on the granite of Pilot Knob and with sill lower than the old level. It at first consisted of eleven radial gates, each 10 feet high by 12 feet wide. These do not work well in this water on account of the abundance of débris, which causes the gates to jam. Recently two of the gates were removed and a Stoney sluice-gate was built in their place with sill 5 feet lower.

Other Works. The design of the canals and structures does not call for much remark, as most of the latter are of timber, and, for the main canal, the Alamo River is used. The biggest wooden structures are the weir across the Alamo, the check (with a drop of 15 feet) where the Western canals branch off, and the huge flume carrying the main Western canal over New River. The East-side main canal tears down the country at a steep slope. A branch goes off to Holtville, where the water is dropped through a power-house to the Alamo channel. Lower down, this water (augmented by the water escaping through the weir higher up) has been dammed up since the closure of the gap in 1907, and two canals are supplied on the west, the excess water being passed over an escape with 28-foot drop back to the Alamo channel. This drop is one of the few reinforced concrete structures in the scheme, and shortly before my visit it had partially given way. All the structures except the head-gates are founded on soil, as there is no rock in the whole area.

Head-Gates for Small Streams.

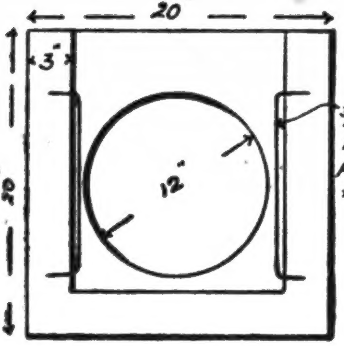
Ready-made concrete head-gates for small irrigating streams are extensively used, and are very simple and cheap structures and different from those described in other schemes. Fig. 47 shows two common types. They are made of plain cement concrete in sizes from 4 inches to 24 inches diameter by several cement works on the scheme. Each head-gate consists of a vertical face built in one piece with a 2-foot length of pipe usually of 1½-inch thickness.

The gate itself is a plain piece of thin galvanized iron, which slides over the end of the pipe in a slight recess in the face. The slide is held against the face by some sort of spring built into the face. The simplest form of spring is shown in the top of the figure, and consists of a $\frac{3}{16}$-inch wire bent so as to press the slide against the face of the concrete. Two thin rolled galvanized sheets sometimes take the place of the wire. For fixing to the concrete at the site, a more elaborate form of spring (shown in the sketch on the right at the bottom of the figure) consists of a galvanized sheet with ends rolled in the same way as for the small gates for furrow-irrigation shown in figure 45, and described in the Redlands scheme. This galvanized sheet is soldered to a short length of pipe or, as shown in the sketch, is bolted to a small cast-iron flange which in turn is embedded in the concrete face either in the shops or at the site.

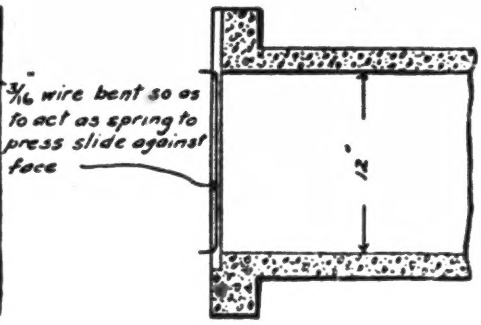
The first type, with wire spring, is the cheapest, and the price of a complete gate (with the cement face and 2-foot concrete pipe) is for 6-inch $1.15 (weight 65 lb.), and for 12-inch $1.75 (weight 180 lb.). The price of the K.T. type of gate (made by Kellar Thomason Co., Los Angeles) without concrete is for 6-inch $1.00, and for 12-inch $1.50.

IMPERIAL VALLEY SCHEME.

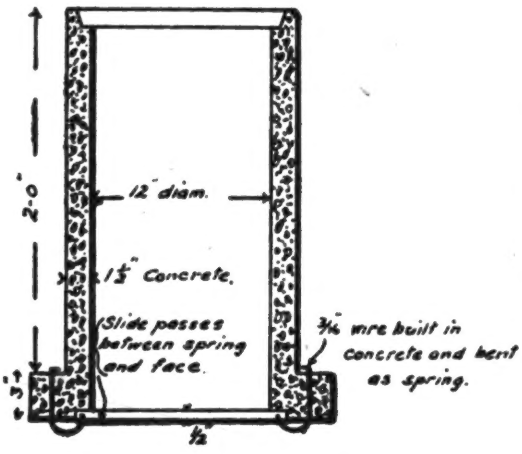
TYPE OF GATE WITH WIRE SPRINGS.



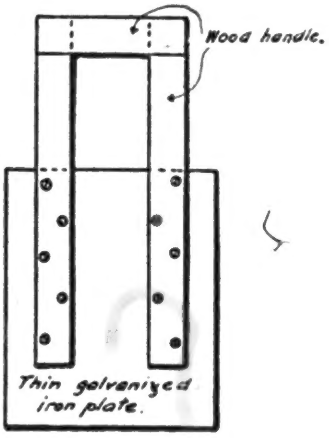
FRONT ELEVATION. SLIDE REMOVED.


3/16" wire bent so as to act as spring to press slide against face
12"

VERTICAL SECTION.

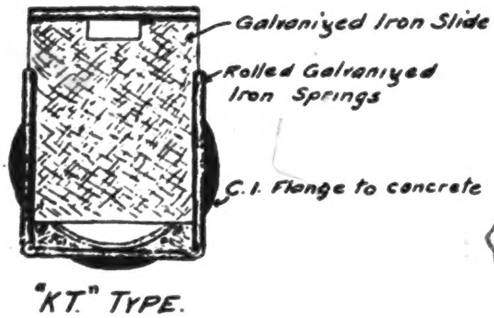

2'-0"
12" diam.
1½" Concrete.
Slide passes between spring and face.
3/16 wire built in concrete and bent as spring.
3"
½"

HORIZONTAL SECTION ON CENTRE LINE.


Wood handle.
Thin galvanized iron plate.

SLIDE.

READY-MADE CONCRETE HEADGATES FOR IRRIGATING CHANNELS.


Galvanized Iron Slide
Rolled Galvanized Iron Springs
C.I. Flange to concrete

"KT." TYPE.

Fig. 47.

The pressure of the springs keeps the slide in any position and allows of regulation.

Road Making. A method of making and maintaining country roads is worth mentioning. Like our Zak River soil, the natural surface makes a very good road for a short time after flooding, but then it breaks up into "chuck-holes" (our Dutch "slag-gate"). The roads are therefore made in duplicate, running parallel and separated by a ridge. While the one road is in use the other used-up road is flooded with water. This levels and hardens it up, making it a good road by the time the other is worn out and ready to be flooded and renewed in its turn.

Cleaning of Canals. On account of the silty nature of the water and the warm climate (which encourages the growth of weeds) cleaning of canals is a much greater task here than on any of the previously described schemes. As in India, the process of cleaning is divided into two separate operations, namely, silt-clearance, chiefly from the bottom, and berm-cutting of the sides. The heaviest silt-clearance is at the head of the main canal, and the berm-cutting is a big work on all the canals, especially the smaller, or where, as in the Western main canal, the slope is very slight or the original capacity is greater than the demand. Small willows, tules, and other weeds grow rapidly and thickly along the berm, and often, as in India, have to be cut twice a year. The Western main canal was originally constructed with a width of 75 feet, and has now silted up to a width of only 30 feet. The silt-clearance at the head is done by huge suction dredges, and along the larger canals by floating dipper dredges. The berm-cutting is done in a variety of ways. All clearing, except for the smallest canals, must be done while the water is running, as the supply can never be shut off entirely. A common instrument used is a huge excavator which travels along the bank with a clamshell dropping bucket. A specially designed instrument, known as a "V," is also used and is pulled along like a plough by traction engines on the bank.

Agricultural Conditions.

Soil. The soil conditions are entirely different from those of other Californian schemes, where, as we have seen, a sandy type predominates. Here the bulk of the soil consists of clay and fine silt. It has been pointed out that the irrigated area was formerly part of the Gulf of California, which has been cut off and partially filled with silt from the Colorado River. Boreholes have been put down to 600 feet without getting to the bottom of this alluvial soil. As most of the deposit was made in a quiet sea, it is naturally found that the bulk of the underlying soil is a compact clay. At intervals throughout the depth horizontal sandy layers are found, which must have been deposited in shallow running water.

The process of soil formation can be seen at the present day after a flood. Wherever silt is deposited from running water a coarser and more sandy soil is found. Thus, close to the main channels where overflow begins, the sandy type is common, and this is physically the best soil possible. Wherever the silt has been deposited in hollows or in sluggish streams the result is a very fine clay which, on drying, contracts enormously and cracks into large slabs. Such a deposit is shown in photo B, plate 15, and those who are familiar with the silt-deposits of the Zak River in South Africa might imagine that this photo was taken on that river, where exactly similar formations are found. The soil conditions, in fact, on this scheme resemble those on the Zak River very closely indeed. Chemically the soils are very rich and suitable, except for a lack of humus. Alkali is present in the heavy compact soil, but has not caused much damage. The underground water-table is extremely deep, and no great trouble is likely to arise from seepage. Physically the greater area consists of a clayey loam. The underlying soil, which appears at the surface over much of the central area, is very compact and fine and contains about 29 per cent. of clay and 63 per cent. of fine silt. Such soil is not easily penetrated by water, but retains its water long, and deep waterings are necessary. A better soil—containing 14 per cent. clay, 15 per cent. fine silt, and the rest medium and coarse silt with a little sand—covers large areas near the rim, and close to the recent overflow channels a more open soil consisting of coarse silt and fine sand is found in the top three feet, overlying the clay loams, and this is physically the best soil of the valley.

Slope and Methods of Irrigating.

The surface slope over the irrigated area is very slight and varies from 5 or 6 feet per mile in the hollow parts to about 25 feet per mile near the side. It is generally steep enough for irrigation by surface-flow between borders, which is the usual method adopted. The beds are usually about 60 feet wide and very long, sometimes half a mile in length. The irrigating stream for such beds is about 4 to 5 cusecs, and the ready-made concrete gate is also used for admitting the water. We might expect that with such gentle slopes irrigation by basin soakage would be more generally practised, as the cost of levelling would be slight, and deeper wetting could be obtained in this way. It is said, however, that there are two objections to this method, namely, that water standing on the surface for a long time in the extreme heat of summer is harmful, and silt deposited on the leaves of young plants is damaging.

Crops.

The scheme is at present able to irrigate about 300,000 acres, of which about three-quarters was irrigated in 1912. The proportionate areas under the various crops are roughly as follows:—

Lucerne	40 per cent.
Cereals	30 „
Cotton	14 „
Maize, Mealies, Fruit, and Vegetables	16 „

Lucerne occupies the biggest area and does very well. Five or six cuttings are obtained per year, giving an average annual return of about 5 tons per acre. It realizes about $9 per ton baled, but is largely used locally for feeding stock. Autumn sowing gives best results. A peculiar feature of the growth of lucerne, which is noticed here and in other hot climates, as on the Salt River scheme, is that at the hottest time of the year—in August—the lucerne passes through a relatively dormant period, when the growth is much less rapid than in the early or late summer. Of cereals, barley is chiefly grown. Cotton is extensively grown, and the area under this profitable crop is increasing very rapidly. It is an annual here, being planted in April and picked from September to the end of the year. It is planted in rows about 4 feet apart and is irrigated by the furrow method. The usual variety is "Mebane Triumph," though Egyptian cotton is also grown successfully. The average return is one bale (500 lb.) of ginned cotton per acre, which sells at about 20 cents per lb., giving a gross return of $100 per acre, and in addition the seed brings in about $8, being used for oil and fodder.

The melon crop deserves particular mention, as about 3000 acres are given to it annually. The reason for the success of this crop is that owing to the warm climate melons ripen much sooner here than in other parts of America, and, being the earliest on the market, realize high prices. Both water-melons and musk-melons are grown, but chiefly the latter (known as cantaloupes), and the "Rocky Ford" cantaloupe is famous throughout America. The seed is planted towards the end of February, and the harvest lasts for eight weeks in May and June. About 4000 truck loads are sent off in this short period by co-operative associations. The average return per acre is about 100 crates (1 foot × 1 foot × 2 feet, weighing about 60 lb.). A crate sells at about

$2.50 in distant markets, and, after deducting cost of freight, refrigerating, commission, and co-operative costs, brings the grower about $1 gross return, i.e. $100 per acre. Good co-operative organization and promptness on the part of the railways are essential for the success of this crop on such a large scale.

It should be noted that the trees which have been found to thrive best under the conditions here are *Eucalyptus tereticornis* (narrow-leaved variety) and *Eucalyptus rostrata*. The latter has been proved by experiments in California to be the most successful eucalyptus in alkali soil, making good growth in soil with a percentage of carbonate of soda as high as .07 in the top 3 feet. In addition it is a good frost-resister and a valuable timber tree. This variety has therefore recently been planted in an experimental plot at Van Wyks Vlei (Cape Province), where the alkali percentage is high, and it appears to be doing very well.

Settlement and Cost.

Like the Fresno scheme, this scheme was financed and constructed by a company who sell water-rights at a price per acre, and also make an annual charge for water supplied. In the Fresno area, however, all the land was privately owned long before the inception of the scheme. Here, on the other hand, practically none of the land was occupied, and, indeed, settlement was all but impossible without the scheme. The area was in fact a desert and open to "desert entry," which allows any citizen for a merely nominal payment to settle on a maximum area of 320 acres of land, which, after conditions of residence have been fulfilled, becomes his property. It was in this way that the land was taken up. Unlike the Government Reclamation or Carey Act schemes, there was no obligation on the part of the settler to buy water-rights, nor did the act of settling within the area commanded by the scheme entitle him to any share of the water without payment. As a matter of fact, residence was impossible without a supply of water, and therefore practically all settlers were obliged to buy water-rights from the company. There was no Government control to protect the interests of the settlers and to see that a proper scheme was constructed.

The developing company owned no land in America; they merely constructed the scheme. The intake being in America, right of diversion was simply obtained by appropriation. The right to pass through Mexico was obtained with some difficulty, and on condition that portion of the water be supplied to Mexican land and a separate Mexican company be formed for operating in Mexico. Construction was begun in 1900, and settlers soon flocked to the scheme. All went well until the river broke through in 1905, and this was the beginning of the disaster which ended in the bankruptcy of the developing company. The operations involved in keeping out the river proved enormously expensive, and after the developing company had exhausted their funds subscriptions from the settlers were collected. Then the Southern Pacific Railway came to their assistance with men and equipment, and expended some three million dollars, the Federal Government also advanced a million dollars, and now, in 1914, after the river broke through near Volcano Lake, the Federal Government is being appealed to again for further funds to save the valley. In addition, a judgment for half a million dollars was given against the company for flooding out certain salt works which existed on Salton Sea before the floods of 1905-07. All these claims against the original developing company forced them to become insolvent, and since 1909 the management of the whole scheme has been in the hands of the Receiver. In 1911 it was decided to form an irrigation district, which will eventually buy out the scheme and run it in the same way as the Modesto-Turlock scheme, but there will probably be considerable difficulty in assessing the capital to be covered by bonds and in marketing these, and it is hard to see what will be the final method of control. In spite of this terrible confusion in management the settlers continue to grow their crops successfully and the cultivated area is continually expanding.

The original developing company constructed and maintained only the main system, the smaller distributaries being in the hands of the settlers, arranged in eight districts of various sizes. The water-rights were sold as shares per acre, at first for $8.75 and later for $20, and at an average of $12 per acre. Each share entitles the holder to an annual supply not exceeding 4 feet per acre, but he has to pay by volume for all water used at the rate of 50 cents per acre-foot, and for at least 1 acre-foot per share annually whether he uses the water or not. In addition to this the annual maintenance and operation charges in each district have to be paid, and these amount to about $1.50 per acre.

The settler's total payments for water per acre are therefore:—To the developing company about $12 for water-right and an annual payment in proportion to water used (with a minimum of 50 cents, even if no water be used), and to the district in which he is located an annual operation and maintenance charge of about $1.50 per acre. Assuming that the average application is about 3 feet per acre, the total annual payments of the settler will be $3 per acre. The measurements of water for payment are made at the farm, but the developing company supplies to the districts at their boundaries and allows an average loss of 10 per cent. in reaching the fields, which is less than the actual loss. The above method is still in use under the management of the Receiver, who acts for the insolvent developing company. Measurements of canal-flow are made by careful current-meter observations and of delivery to farmers chiefly by submerged orifices. An electrically-operated rating trough 200 feet long is used for checking the current-meters, which are liable to rapid wear on account of the silt in the water.

The average annual application at the fields is about 3 feet, and at the headworks about 4 feet.

CHAPTER XIV

THE YUMA SCHEME

(United States Reclamation Service)

THIS scheme also derives its water from the Colorado River. The headworks are about 20 miles higher up the river than the Imperial intake. The lands irrigated are the low alluvial lands bordering the river; they extend on the right bank to near the Imperial intake, and on the left bank from Yuma down to the borders of Mexico. The elevation of the irrigable river lands is from 90 to 140 feet above sea-level. The lands on the right bank are bordered by high rocky mountains, and on the left bank by a bench about 80 feet higher, part of which is to be irrigated by a pumping plant. The climatic features are similar to those of the Imperial scheme.

Outline of Scheme.

The headworks consist of an overflow-weir of the Indian type built right across the sandy bed at a place where the river is confined by rocky banks on both sides. Most of the irrigable land is on the left bank below Yuma, but, as the large and meandering Gila River would have to be crossed on this side, it was decided to carry the main canal down the right bank for nine miles to Yuma and then cross the Colorado River by means of a syphon. Most of the land, being very low, was liable to inundation in high floods, and the river tended to change its course in the same way as described in the previous scheme. Consequently, expensive levees have been built to keep the river within a defined channel. The most interesting and expensive works are the weir, the syphon, and the levees.

Head-works (the Laguna Weir).

The bed of the river consists of sand and gravel in the main channel and silt towards the sides, the whole length from rock to rock being about 1600 yards. The type of weir is somewhat similar to that commonly constructed across the big rivers in the Indian Punjab, which also run in wide channels without rocky bottoms. The essential feature of this design is a long flat paved slope of rock on the down-stream side of a crest-wall with other parallel cut-off concrete walls. In India the upper cut-off wall is usually founded on a continuous line of masonry wells sunk deeply into the soft bed. In this work 6-inch sheet-piling was driven 12 to 32 feet deep, and the wall was built on this. Sheet-piling was also driven in weak places under the other two cut-off walls. The down-stream slope is 1 on 12 (usually 1 on 15 in the Punjab weirs) and the drop from crest-level to toe 13 feet. Down-stream is a 40-foot apron and up-stream is a 1 on 2 slope of large rock. The level of the down-stream toe is 138, which is 3 feet below low-water level and about 5 feet below the general bed-level outside the main channel. The toe-wall was carried down to 131, making a 7-foot wall with bottom 12 feet below the bed-level outside the main channel. The other two walls were only 10 feet high, except in the main channel, where the up-stream wall was to be 19 feet high, but, owing to scouring before closure, reached a maximum of 40 feet. In this part much more rock was dumped up and down stream. Rock was dumped between the concrete walls and covered with an 18-inch concrete pavement. No falling shutters are provided on the crest as in the Punjab weirs.

Head Regulators.

The canal-intakes are on the rock at the ends of the weir, and are designed in such a way as to prevent silt from blocking the entrance or entering the canal in excessive quantities. The silt difficulty is a great one, as may be gathered from the fact that the whole lake above the weir was practically filled up with silt within the first year after completion of the weir. The head-gates consist of a large number of 7-foot 6-inch openings closed by horizontal flashboards, so that only the top waters, which are comparatively free from silt, enter the canal. The line of the openings runs nearly parallel to the river, and a clear deep channel is maintained along the face by means of deep sluice-gates placed just below the lower end of the intake. The sills of these

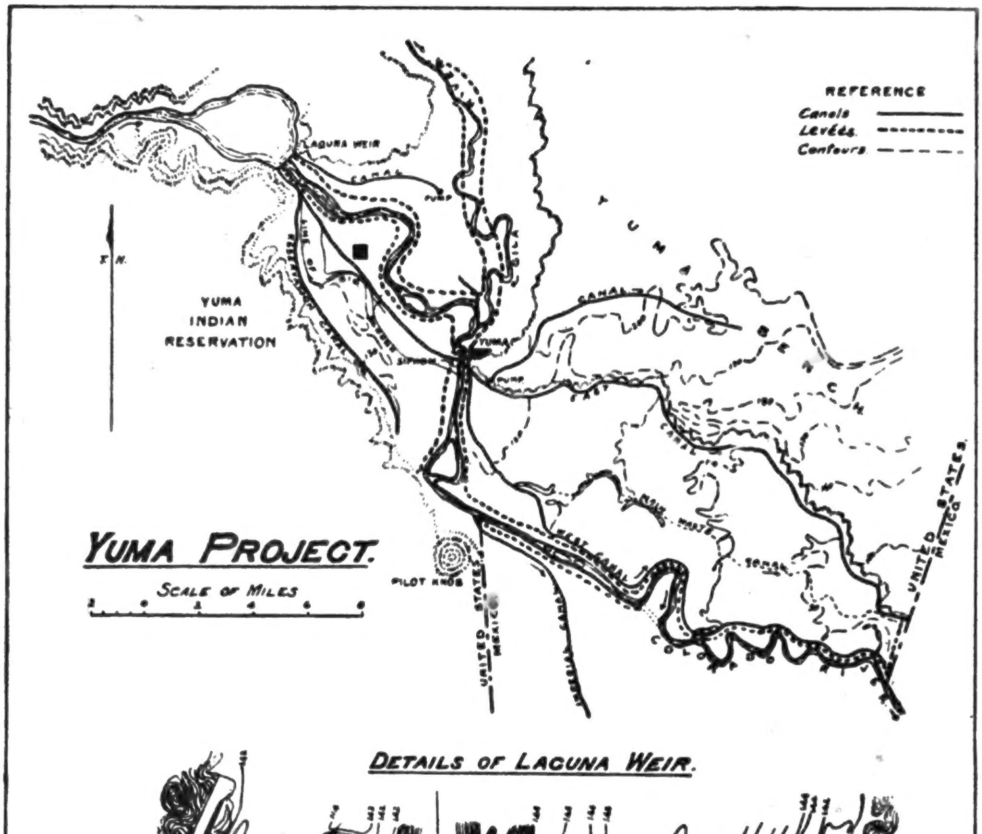

YUMA PROJECT.
SCALE OF MILES
2 0 2 4 6 8
REFERENCE
Canals
Levées
Contours
LAGUNA WEIR
CANAL
PUMP
N.
YUMA INDIAN RESERVATION
YUMA
SIPHON
PUMP
CANAL
YUMA MESA
EAST CANAL
WEST CANAL
PILOT KNOB
UNITED STATES
MEXICO
COLORADO RIVER
DETAILS OF LAGUNA WEIR.
Regulator
Canal
El. of Crest 151
El. of Apron 139
Regulator
PLAN OF WEIR
Scale of Feet
Crest El 151
Paving mostly Concrete 18" thick but in places stone 2' to 3' thick
El 146
Slope 1 on 12
Rock-fill
Large Rocks
Gravel and Sand
El Low Water 1900
246'-0"
DESIGNED SECTION ON A-B IN MAIN CHANNEL.
Scale of Feet
Crest El 151
Paving mostly Concrete 18" thick, but in places stone 2' to 3' thick
Rock-fill
Slope 1 on 12
Original Ground Line
Concrete
Sheet Piling
Gravel and Sand
Apron
57'6"
93'6"
SECTION OUTSIDE MAIN CHANNEL
10 0 10 20 30 40
Scale of Feet.

Fig. 48.

sluice-gates are 13 feet below crest-level. They are of the Stoney type, 18 feet high and 35 feet wide, and are operated by electric motors. There are three of these gates on the right bank separated by 8-foot piers, and one on the left bank. The general arrangement of the sluice and intake on the left bank is shown in photo B, plate 16.

The cost of the weir was $1,673,000, and of the intakes and sluices $352,000, or a total of over two million dollars for the headworks, The work was commenced in 1905, and took nearly four years to complete. It was commenced by contract, but after the failure of the contractors was completed by Government.

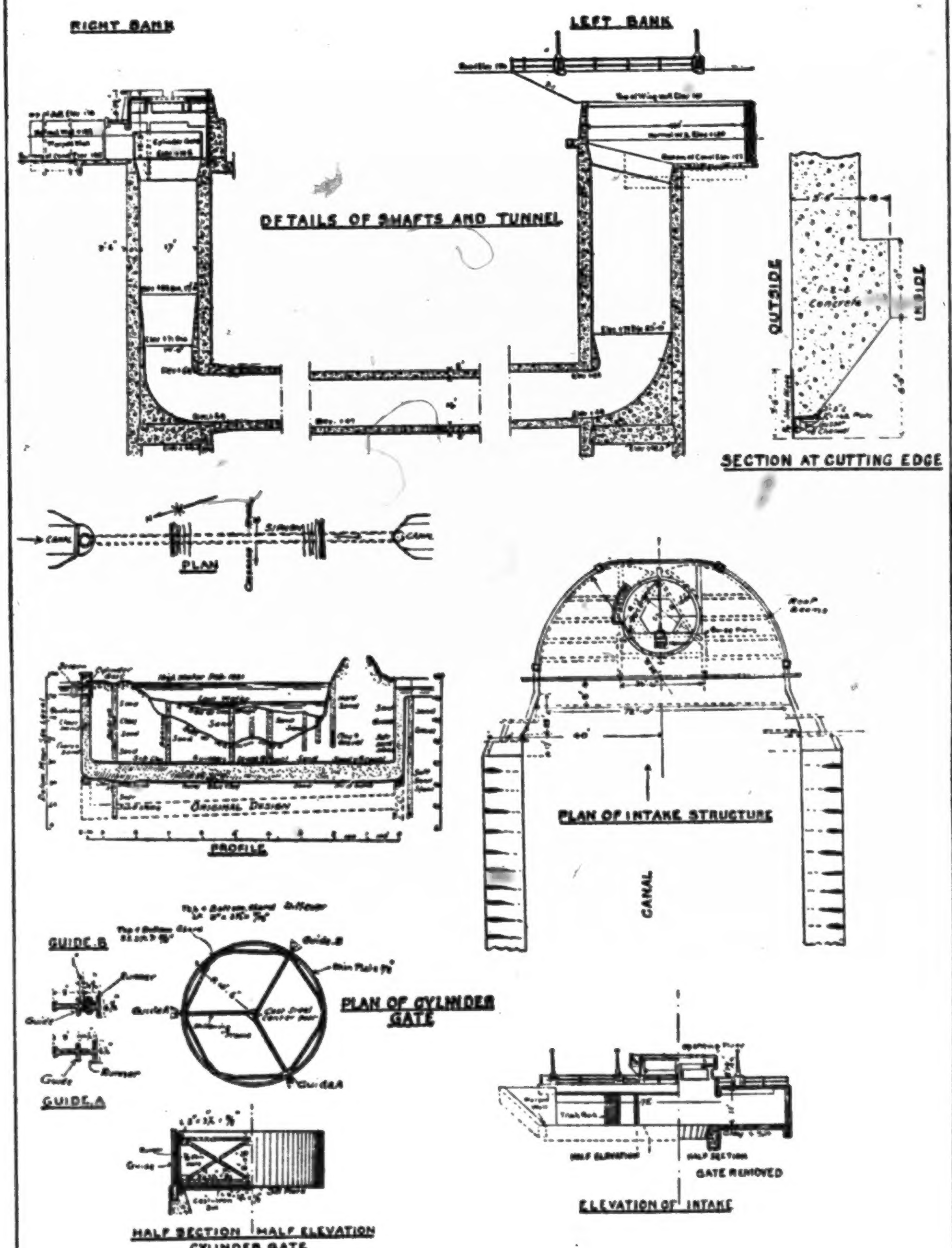
Canals.

The canal on the left bank is small and serves an area up to the Gila River.

The main canal on the right bank has a bed-width of 84 feet and full-supply depth of 7 feet, with a slope of 1 in 5700 to the end of 1½ mile (where a large branch takes out for irrigation) and thereafter a slope of 1 in 10,000. A 12-foot drop is given in one place. The canal is badly silted on the sides, chiefly because it has usually carried very much less than its full capacity, the proportion of the whole area developed being very small. Several very sharp bends are given in the canal, and the silting on the inner side of the bend is usually very heavy. A check and escape to the river are provided shortly before the syphon.

Colorado Syphon.

The syphon under the Colorado River crosses at Yuma, where the river is fairly narrow with high ground on the left bank. It has to pass a full-supply of 1400 cusecs through 410 yards of pipe, with a loss of head of 2 feet. Details of this great structure are given on fig. 49. The pipe had to be placed very deep under the river because the bed is liable to great changes, being scoured out to a depth of as much as 30 or 40 feet during floods and silted up again in low-water periods. It was originally intended to carry the pipe so low as to be in a soft sandstone (located by borings) in the hope of being able to carry on the work without compressed air. It was found during construction that this was impossible, and the pipe was actually carried through at a higher level. The syphon has two vertical wells at the ends, the intake-well having a diameter of 17 feet, and the outlet-well of 23 feet, the tunnel connecting them having a diameter of 14 feet and a drop of 2 feet from both ends towards the centre. The vertical wells were built on a steel cutting-edge. As the latter descended, the well was built up in sections 3 feet 6 inches high. At first the excavation inside the well was done by hand, but when water was encountered,

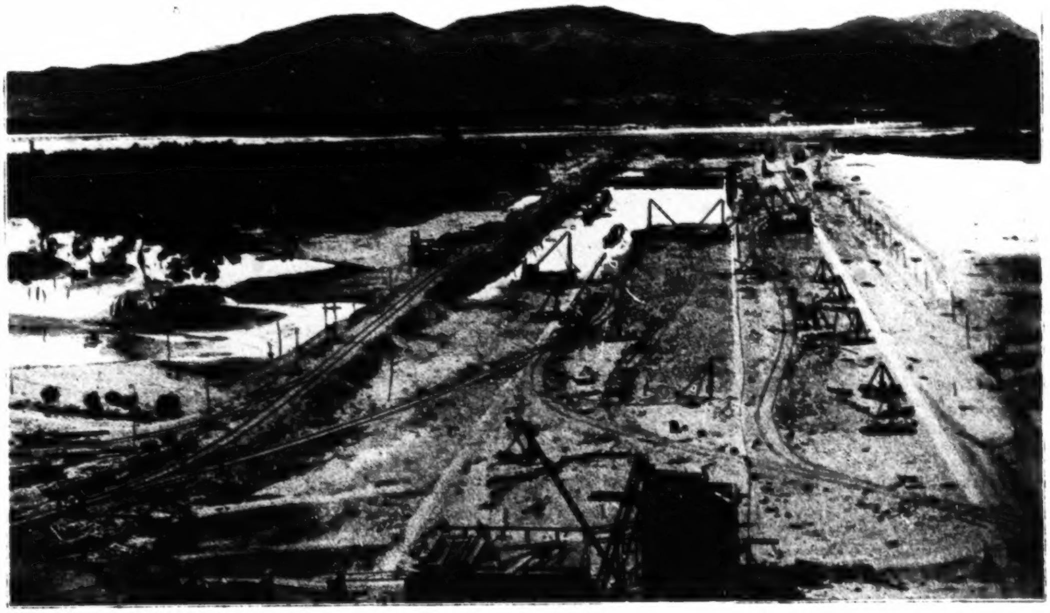

RIGHT BANK
LEFT BANK
DETAILS OF SHAFTS AND TUNNEL
OUTSIDE
INSIDE
1-2-4 Concrete
SECTION AT CUTTING EDGE
CANAL
PLAN
CANAL
Roof Beams
PROFILE
ORIGINAL DESIGN
PLAN OF INTAKE STRUCTURE
CANAL
GUIDE B
Runner
Guide
Guide
Runner
GUIDE A
Guide B
Guide A
Skin Plate
PLAN OF CYLINDER GATE
Guide A
HALF ELEVATION
HALF SECTION
GATE REMOVED
ELEVATION OF INTAKE
HALF SECTION
HALF ELEVATION
CYLINDER GATE

YUMA SCHEME

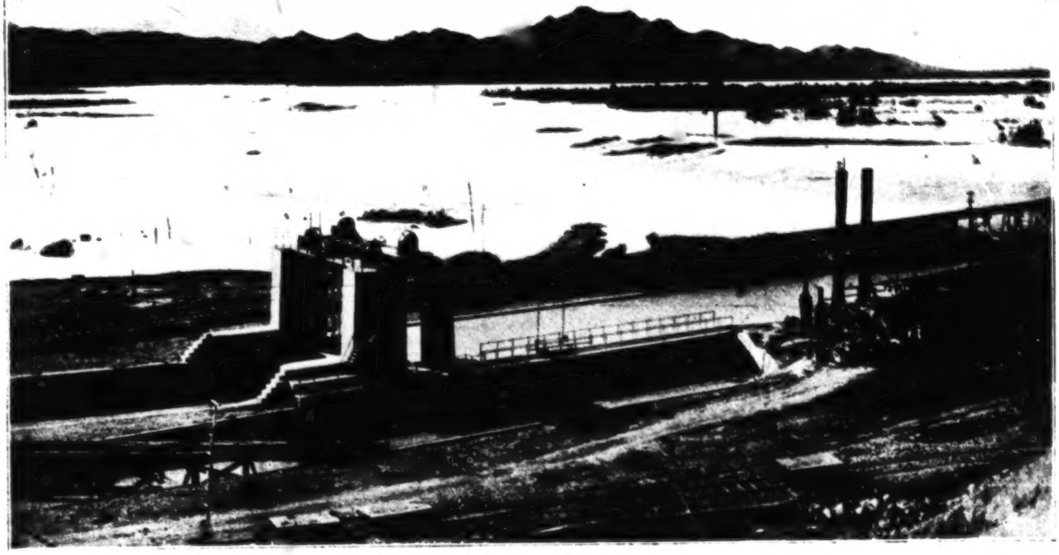
SIPHON THROUGH COLORADO RIVER

Fig. 49.

YUMA SCHEME—Laguna Weir.

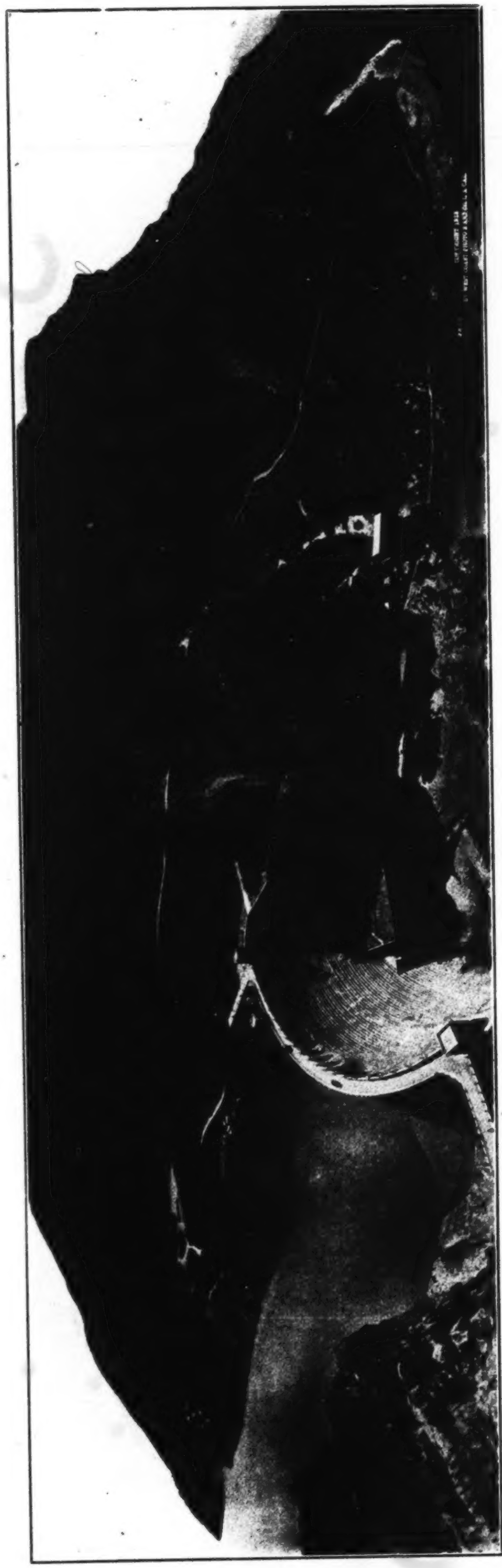


(*a*) Weir during construction, from left bank.



(*b*) Weir completed. Left bank Canal Head-regulator, with Scouring Channel controlled by stoney sluice-gate.

Plate 16. **SALT RIVER SCHEME.**



(c) Roosevelt Dam from right bank.

grabs had to be used. These removed the central part of the excavation. The material at the sides and under the cutting-edge was removed by blasting, the dynamite being placed by divers. The well sank by its own weight after the sides were blasted away. The horizontal tunnel was driven by compressed air. The concrete was of strength $1 : 2\frac{1}{2} : 5$.

The gate controlling the entrance to the syphon is of unique design (see fig. 49) and deserves special mention. It is a ring-gate, and has previously been referred to in the description of the Lahontan dam of the Truckee-Carson scheme. Its action is somewhat similar to that of the household bath-plugs of the hollow cylinder type which control the outlet of a bath. In this case the end of the furrow represents the bath and the vertical intake-well of the syphon corresponds to the escape pipe, the ring-gate working on a vertical axis immediately over the entrance. The upper end of the intake-well expands to fit a horizontal circular iron rim which forms the sill. This is at the level of the floor of the canal and in the centre of the bay in which the canal ends. Over the sill the huge ring-gate works. It is a hollow cylinder with a diameter of 21 feet and a height of 8 feet. As the full-supply depth in the canal is only 7 feet, no water can enter the intake-well while the cylinder rests with its bottom edge on the sill. As soon as the gate is raised, water enters evenly from all sides and all friction due to one-sided pressure is eliminated. The gate is kept in position by three cast-iron guides (as shown in figure) built in concrete piers which are the only obstructions to the free flow of water to the rim. The weight of the gate is 8 tons, and it is raised by means of an electric motor. The whole work on the syphon was completed about the middle of 1912 at a cost of $661,000, and the syphon is now working very successfully.

Other Works.

Below the syphon the main canal splits into two, one following the high land bordering the river and the other the edge of the bench. The canals are all silted up very much after short use, berms of great size and thickly covered with weeds having formed very rapidly.

The smaller head-gates are usually of wood, but cement pipes similar to those of the Imperial Valley are now being put in.

Extensive levees along the Colorado and Gila Rivers have been constructed, as on the Imperial Valley scheme, to control the river and protect the lands from inundation and erosion. Over 70 miles of levees have been constructed on this scheme at a cost of about $750,000.

The soil along the river consists mostly of the coarser silt recently deposited by the river.

Soils, Slopes, Methods of Irrigation and Drainage.

The soil on the high bench to be irrigated by pumping, is a more open sandy soil. In the alluvial soil near the river, owing to the former overflow of the river, the ground is fairly hummocky like the overflow lands along the Orange River in South Africa, and considerable levelling is necessary. The slope of the alluvial soil is roughly 3 feet per mile and parallel to the river. In spite of this slight slope, the long narrow beds are chiefly adopted, so that the irrigation is by slow surface-flow between borders instead of by basin-soakage. Probably the amount of silt in the water is against the basin method, and, even with the long beds, I noticed a fairly thick crust of silt on most fields after irrigation, which, on drying, cracked into flakes with curled-up edges. The length of the beds is about 300 yards, and the width 60 to 120 feet. The scheme is still young, and it may be found later that shorter beds forming basins are more economical of water. Such long beds, when the slope is so small, are only possible with large irrigating streams, and on this scheme 12 cusecs is the standard stream supplied to an irrigator at his farm, though he sometimes divides this into two or three streams. Seepage has already begun to appear, especially on the right bank, and the construction of a drain has been started which will run right down the irrigable area on this side, partly in open cutting and partly in pipes at a slope of 1 in 1000 discharging into a sump emptied by pumps.

Agricultural Conditions.

The scheme is too young to give any results of crops, the bulk of the lands on the left bank below Yuma having been irrigated from the main canal for the first time in 1912-13. The total area cropped in 1912 was only 10,000 acres. More than two-thirds of the area was given to lucerne. Barley occupied a fair area, and other crops were maize, mealies, sugar-cane, vegetables, fruit, and cotton. Oranges will probably do well in the more open soil of the upper bench. A few farmers run ostriches on their lucerne as a business proposition. The breed is not good compared with the best South African birds. About six birds are run to an acre, and I saw about thirty birds camped off in breeding camps about 30 yards by 60 yards. Usually two hens, but sometimes three, were placed with one cock. The first eggs of the season hatch out well, but later in the season many failures result. Chicks were selling at about $100 each at six months old.

Settlement and Cost.

The whole area proposed to be irrigated by the scheme is 131,000 acres, of which 46,000 are high lands to be irrigated by pumping. Of the total area, about 57,000 acres were in private ownership, and part of these lands were irrigated in a rough way by flood furrows and pumps before the scheme was commenced. 6500 acres of the lands on the right bank were in an Indian Reservation which was thrown open to settlement in 1910 in 20 and 40 acre farms and quickly taken up. As the syphon was completed only in 1912, the area developed is at present very small, and the area under water-right application or rental contracts in that year was only 16,000 acres. The limiting area on the private lands is 160 acres, and on the Government lands 40 acres. The building-charges are $55 and $66 per acre, but at present the bulk of the settlers are being supplied on a rental basis, as their areas have not been officially declared open. The water rental is 50 cents per acre-foot used. In addition, an annual operation and maintenance charge of $1 per acre is made. The actual cost in 1912 was $7.30 per acre irrigated, but this should be considerably reduced as the irrigated area increases, silt-clearing and berm-cutting being very costly when the canals run at less than full supply. The whole cost of the scheme to date is about six million dollars, and the cost of the pumping scheme for the high bench-lands (not yet started) is not included. There is apparently no great rush of settlers to take up new lands.

Distribution of Water.

In order to run the minor canals full and to irrigate with the large streams used, a system of rotation is essential. The present system is a 7-day rotation. The stream supplied to each irrigator is 12 cusecs for such time as will allow a 6-inch watering to the area to be irrigated. The rotation usually begins at the bottom and works up the minor, one reason for this being that breaks in the bank are fairly frequent on account of burrowing animals, etc., and by starting from the bottom there is usually land requiring irrigation above the break on to which the water can be turned without loss or shutting down the minor. Two waterings per month are usually given to lucerne. Nominally, the settlers are limited to an annual application of 5½ feet. In 1912 the average application at the fields was nearly 9½ feet, and, measured at the intake, nearly 15 feet. These figures are very high compared with the Imperial Valley scheme, but will probably be reduced, as much of the land has received only a rough preliminary levelling.

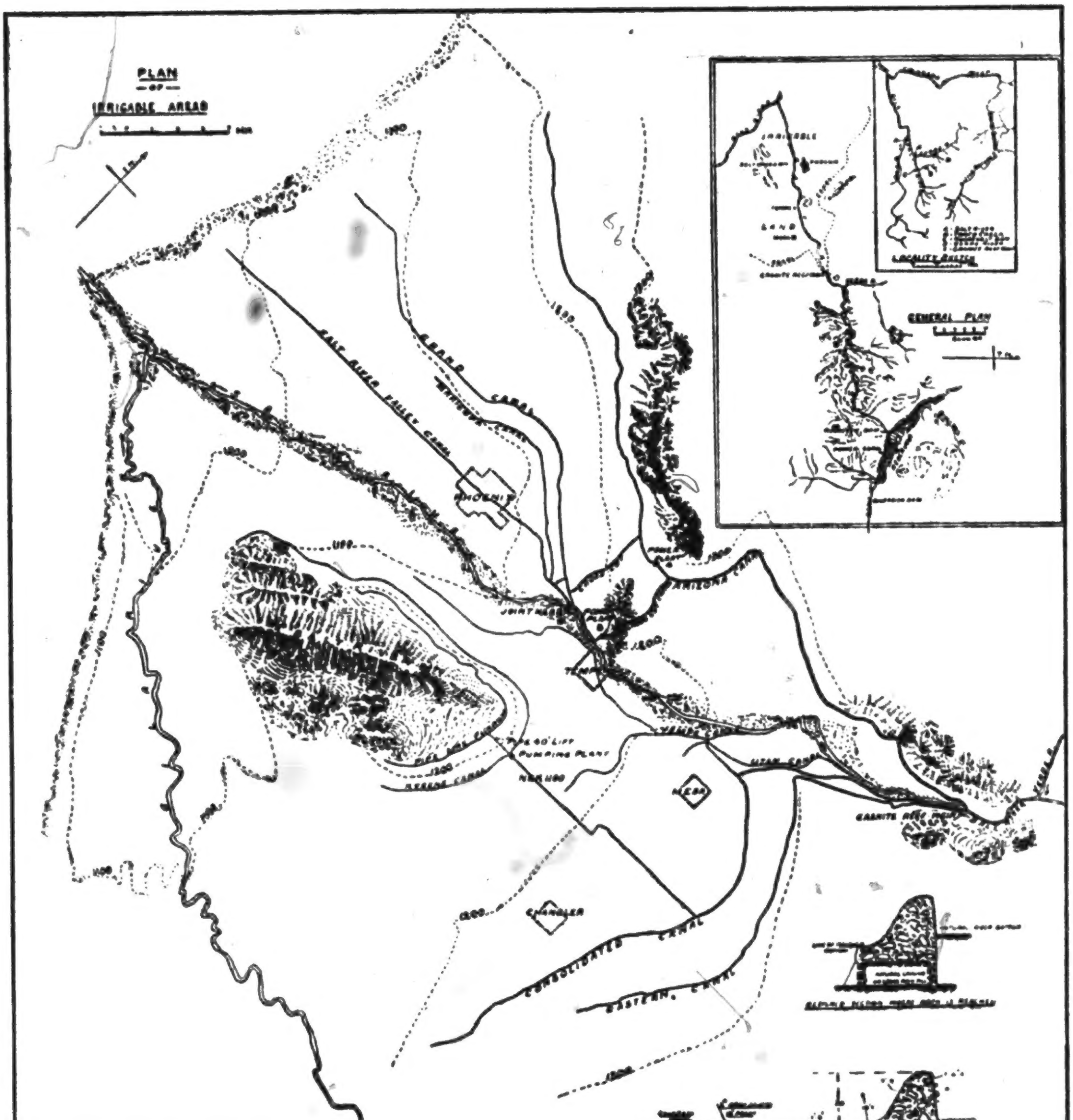

PLAN
OF
IRRIGABLE AREAS
SALT RIVER VALLEY CANAL
GRAND CANAL
PHOENIX
ARIZONA CANAL
JOINT HEAD
TEMPE
1200
1300
PUMPING PLANT
MESA
UTAH CANAL
CHANDLER
CONSOLIDATED CANAL
EASTERN CANAL
GRANITE REEF DAM
GENERAL PLAN
LOCALITY SKETCH
CROSS SECTION OF GRANITE WEIR
SALT RIVER SCHEME

Fig. 50.

CHAPTER XV

THE SALT RIVER SCHEME

(United States Reclamation Service, Arizona)

THIS scheme is situated on the Salt River, just above its junction with the Gila River, which, as we have seen, enters the Colorado River at Yuma. The irrigable lands are at an elevation of between 1000 and 1300 feet and on both banks of the Salt River, beginning where the river emerges in a more open plain after passing from Roosevelt dam through fifty miles of mountainous country in a gorge.

The annual rainfall over the irrigable area is about 8 inches, and over the catchment area above the Roosevelt dam about twice as great. The rain falls both in summer and winter, the summer rains being sharp and heavy showers. The temperature ranges from 22° to 117° F. The climatic conditions are therefore very similar to the dry parts of South Africa, and, indeed, in the surrounding mountainous formation and the vegetation this area very closely resembles portions of the Kenhardt district bordering on the Orange River. Skirting the area on the north, and cropping out throughout the lands, are masses of old granite with little vegetation and very like the granite hills near Kakamas (South Africa). The vegetation, too (see plate 17A), is strangely like that of Kenhardt district. One conspicuous bush, the *Paola verdi* (evergreen), is exactly like the lemoendoorn boom of Kenhardt. It grows to a height of about 20 feet, and has green bark and thorns and very little leaf. Another thorn tree, the "catsclaw," has short thorns bent back like our "haakdoorn." Cacti, taking the place of our "kookerbooms," are also common, the most abundant and remarkable being the giant cactus, which grows to a height of 40 feet either in a single straight stem or with several branches like a candelabrum. Other forms of cacti are the "cholla," growing up to 7 feet high, with many branches covered with numerous glittering needles, and a low barrel-shaped cactus. Other growths familiar to South Africa are the American aloe with a long stem flowering at intervals of several years, prickly pear, and wild tobacco. A very common bush is "greasewood" (or creosote bush), which grows from 2 feet to 8 feet high, and is dotted fairly regularly over the area. It is a straggling bush, like some South African bushes, having many long slender twisted stems springing from **Vegetation.**

the ground. It has very small narrow leaves. Several of these types are shown in photo A, plate 17. Close to the river arrowweed, willow, and cottonwood are common.

Water Supply.

The drainage area above the diversion-dam at Granite Reef is 12,250 square miles—6000 square miles of the Verde River and 6250 of the Salt River. Above Roosevelt reservoir, 45 miles higher up the river, the drainage area is 5760 square miles. The latter area is mostly reserved against grazing. Its vegetation is, in consequence, fairly well preserved, and the run-off is not so heavily charged with silt as the Verde River, the catchment of which has been tramped out by stock.

The drainage area reaches a height of 10,000 feet, and snow falls on it, but melts early in summer. The greatest run-off is therefore during winter and generally earlier in the year than on other schemes further north.

At Roosevelt the maximum annual run-off in 22 years was 3,260,000, the minimum 154,000, and the mean 808,000 acre-feet.

For the Verde, the maximum and minimum are 1,850,000 and 117,000, and the mean 582,000 acre-feet. The great variation between maximum and minimum run-off is more like our South African rivers, which depend chiefly on rainfall and not on melting snow. The average distribution of the flow throughout the year is roughly as follows:—

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Per cent. ...	10	19	22	12	5	2	3	5	4	3	6	9

At times the flow at Roosevelt is below 250 cusecs, and during high floods has reached 97,710 cusecs, so that storage is essential for irrigating the whole area of 230,000 acres proposed for the scheme. No storage has yet been provided on the Verde River, but on the Salt River the Roosevelt dam was completed in 1911 with a capacity of over 1¼ million acre-feet, or 50 per cent. more than the average annual run-off. It was the need for expensive storage works that brought the Reclamation Service to this area. Irrigation was begun here some forty years ago, and furrow after furrow was taken out until the area embraced by all the schemes was far in excess of the water available without storage, the later furrows obtaining water only during the short periods of high flow. The Roosevelt dam was undertaken chiefly to remedy this state of affairs. Owing to the older rights of those who have not joined in the scheme, the whole flow of the Salt River cannot be impounded in the Roosevelt dam, and it is necessary to pass round the reservoir as much of the flow as, together with the Verde flow, will satisfy these early rights.

Outline of Scheme.

The Roosevelt storage dam is situated just below the junction of the Tonto Creek with the Salt River, where the river enters a deep gorge. A diversion-weir higher up the Salt River feeds a furrow which runs for 19 miles above reservoir full-supply level on the left bank and drops its water through turbines below the Roosevelt dam. The ordinary discharge from the dam can also be put through turbines in a power-house immediately below the dam. The electricity generated here is sent all over the scheme for commercial and irrigation use. Below the dam the river continues in a gorge surrounded by high mountains for 45 miles down to Granite Reef weir. The natural river channel is used to convey the water in this length. The Verde River enters the channel about five miles above the weir and its waters are also picked up by the weir. The Granite Reef weir was completed in 1908 and takes the place of several other older intakes, some higher up the river and others lower down. A large proportion of the canals at present used are those of the old schemes enlarged and improved. The Arizona canal, which formerly took out above Granite Reef weir, is the main canal from the weir on the right bank, and it now feeds the canals, which formerly took out lower down, by cross-cut canals. Similarly, on the left bank, the main eastern canal starts from Granite Reef weir, and, though recently constructed, feeds the Consolidated and other older canals. Most of the older canal systems have been purchased by the Reclamation Department and now form one scheme; but some canals, such as the Tempe and Utah, are still privately operated. Drops in the main canals and cross-cuts are utilized for generating power, and several pumps are operated electrically to raise the sub-soil water for irrigating large areas and also to work a pump which raises the water from the neck at the east point of the Salt River Mountains to irrigate the higher ground round about these mountains.

The Roosevelt Dam.

The Roosevelt dam is built just inside the gorge below the junction of Tonto Creek with Salt River, and when the reservoir is full the water will stand back about sixteen miles up each river, with a width of between one and two miles.

The storage capacity to spillway-level (220 feet above bed-level) is 1,284,000 acre-feet. As the mean annual run-off is only 808,000 acre-feet, it will be seen that the reservoir is not likely to be filled often. The greatest height yet reached is 179¼ feet above bed-level, which

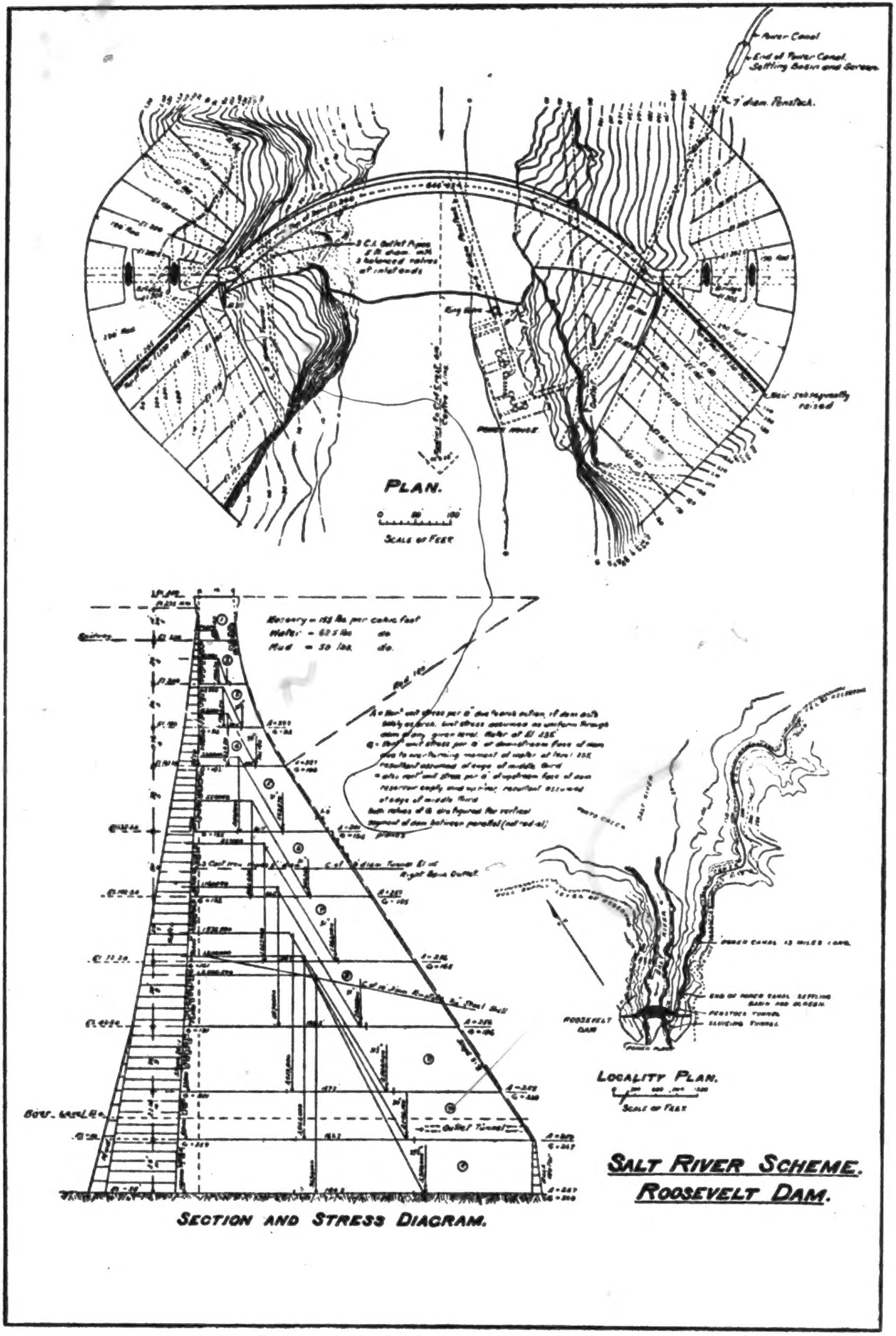
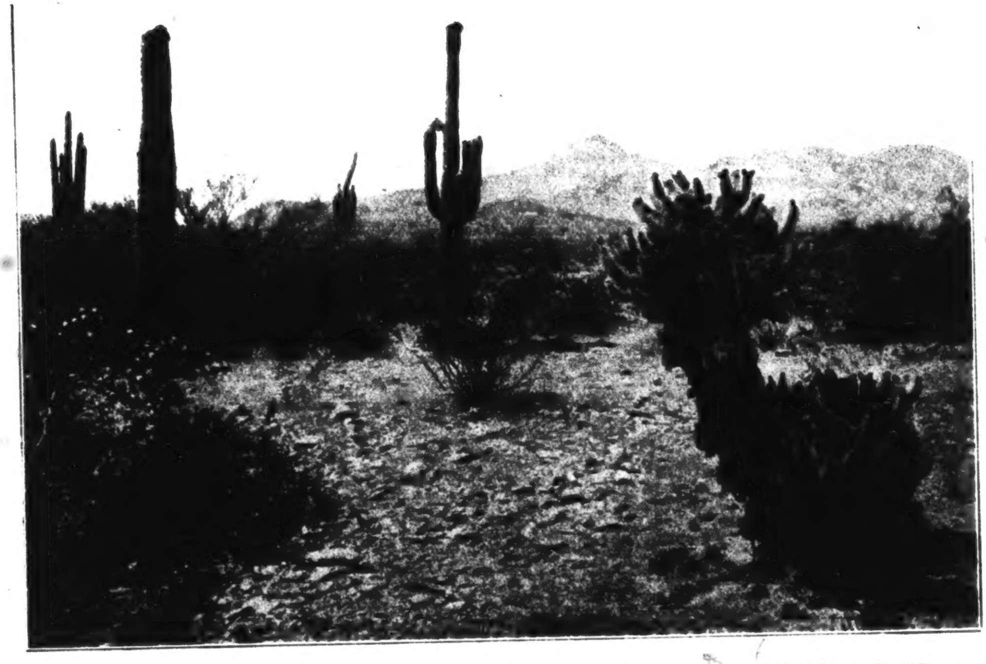

Power Canal
End of Power Canal. Settling Basin and Screen.
7' diam. Penstock.
PLAN.
Scale of Feet
Masonry = 153 lbs per cubic foot
Water = 62.5 lbs. do.
Mud = 50 lbs. do.
Outlet Tunnel
SECTION AND STRESS DIAGRAM.
LOCALITY PLAN.
Scale of Feet
Roosevelt Dam
Power Canal 13 Miles Long
End of Power Canal Settling Basin and Screen
Penstock Tunnel
Sluicing Tunnel
SALT RIVER SCHEME.
ROOSEVELT DAM.

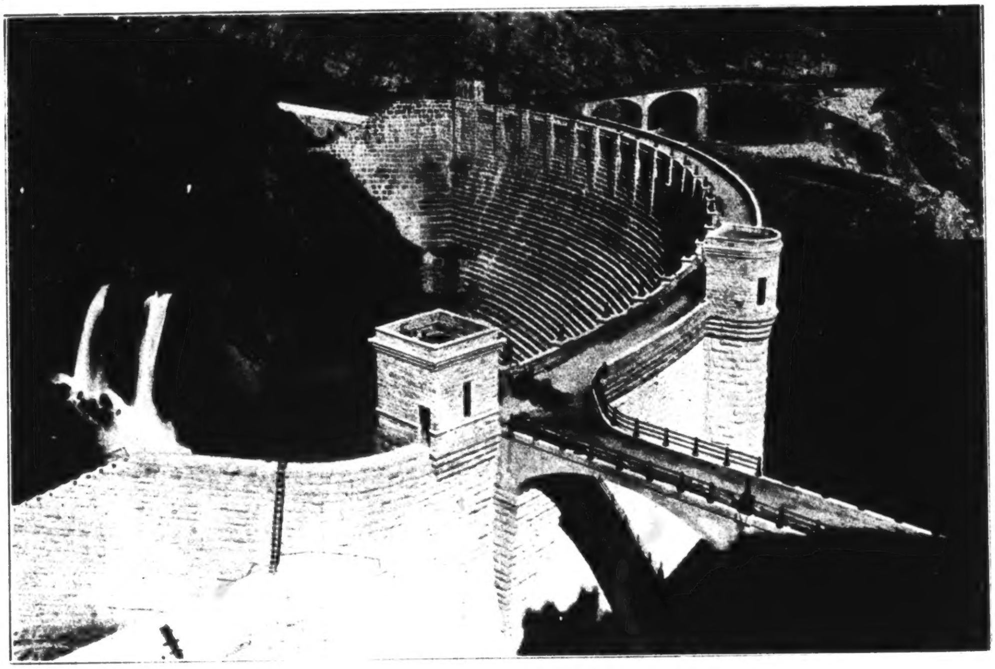
Fig. 51.

R

SALT RIVER SCHEME.



(*a*) Typical Vegetation. Four "Giant Cacti" on left. "Paola Verdi" between two central "Giants." "Greasewood" Bush in centre of picture in front of right "Giant." "Cholla" Cactus on right.



(*b*) Roosevelt Dam from left bank.

Plate 17.

SALT RIVER SCHEME—Roosevelt Dam.

(c) Bed-rock near left bank.

represents a storage of 703,000 acre-feet. Since the completion of the dam, in only one year (1911) did the inflow reach the average. A very dry year was 1913, and, at the time of my visit (in October, 1913), the storage was only about 100,000 acre-feet, the water-level having sunk below the outlet-valves on the right bank which are at 115 feet above bed-level. The gorge, 45 miles long, between Roosevelt dam and Granite Reef weir somewhat resembles the Grand Canyon on a small scale. Near the lower end granite and dolerite are seen, but further up the gorge we pass the typical Grand Canyon formation of highly-coloured coarse sandstones or shales in horizontal layers. Nearer the dam site, quartzite and dolomite predominate, and the dam itself is built on this formation—the broadly-stratified layers dipping up-stream at a gentle slope (see photo C, plate 17). A few hot springs emerge from the rock just below the dam.

Design.

The plan and section of the dam are shown on fig. 51. The dam has been built in the form of an arch with radius of 410 feet (to c.l. of crest) and subtending an angle of 90 degrees at the centre. Spillways are provided on both sides, each 200 feet long and tangential to the curve. They have been formed by huge excavation, and the rock excavated has been used in the wall. Along the crest is a roadway which crosses over the spillways on bridges. The maximum height of the crest above foundations is 280 feet, of which 40 feet is below the original gravel river-bed. On the section is the analysis of stress as published by the Reclamation Department. The maximum vertical stress is 267 lb. per square inch, or a little over 17 tons per square foot. The up-stream face is vertical for 60 feet, and then has a slope of 20 on 1. The down-stream face is stepped and has a curve of 140 feet radius to 77¾ feet below crest, and then a slope of 1.5 on 1 to 250 feet below crest.

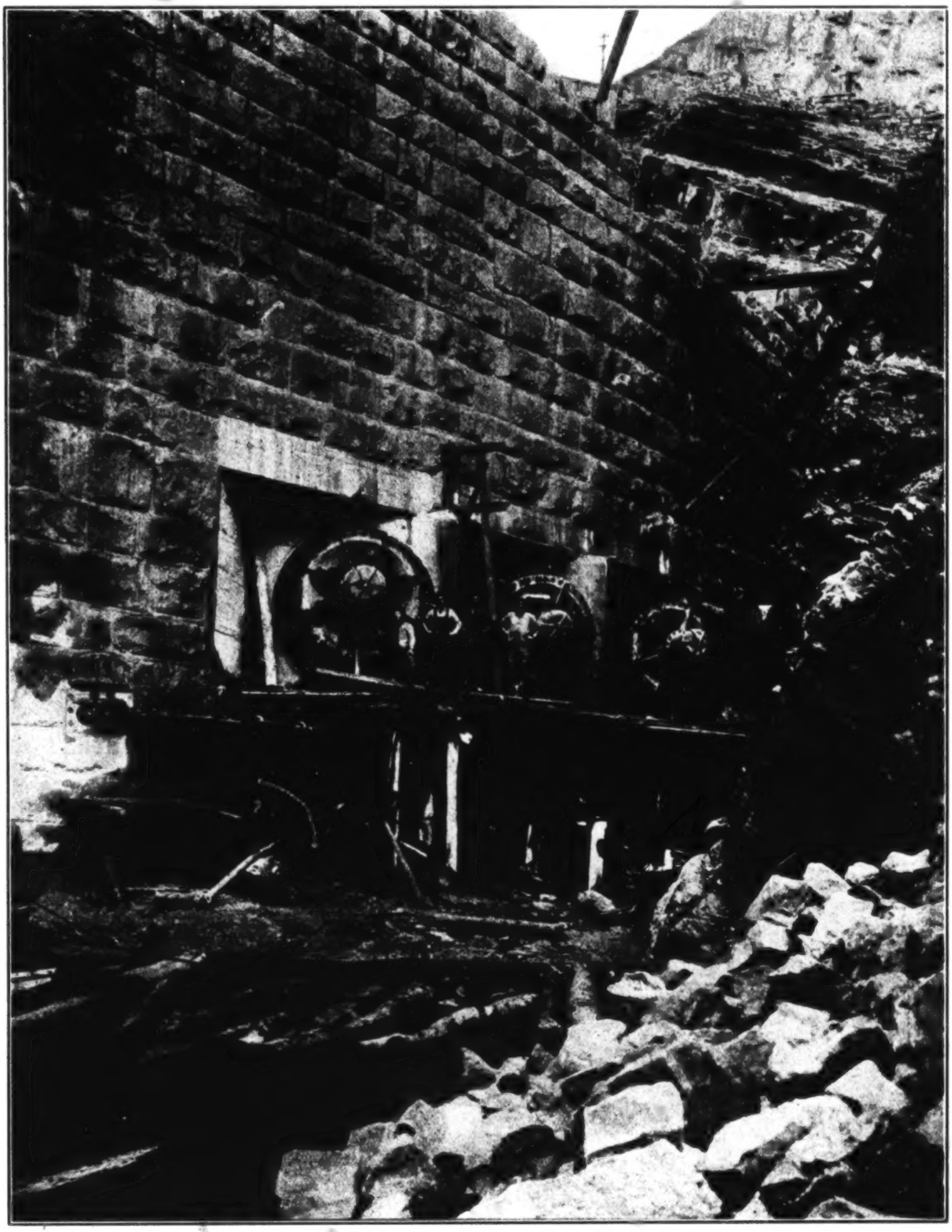
Construction.

The dam was built of cyclopean masonry bedded in concrete, the faces being of dressed masonry. On account of the great distance from railways, and the mountainous nature of the road, which had to be specially constructed for this work, it was decided to erect a cement plant and manufacture the cement for the work at the site. Suitable limestone and clay were found close to the site, and these were used in the proportion of 3 to 1. The complete plant cost $218,000, and its capacity was 350 barrels per day at a cost of about $2 per barrel. Crude oil, costing $3.50 per barrel at the site, was used for fuel. The contents of the dam were 342,000 cubic yards, and the cost was $3,800,000, including $152,000 for submerged lands, but excluding power-plant. Construction was started in 1905 and finished in 1910. It took much longer to build and cost much more than was estimated on account of exceptional floods. It was started by contract, and probably the difficulties with contractors on this and other works (e.g. Shoshone dam) have led Government to do recent large works, such as the Arrowrock and Elephante Butte dams, themselves. The crest of the spillway-weirs was at first built 20 feet below dam-crest, but they have recently been raised by about 5 feet.

Outlets. Several outlets are provided through the dam. The lowest is below bed-level, and consists of a tunnel, 13 feet by 10 feet, driven through the rock of the left bank. This was used for passing water during construction. It is controlled by six Stoney gates, 10 feet by 5 feet, operated by hydraulic rams in a chamber in the dam over them and at the bottom of the valve-tower visible in photos on plate 19. It was found to be dangerous to work these gates with much water in the dam, the velocity being so great that part of the thick steel lining to the tunnel was torn out. Another outlet was therefore provided at a level of 115 feet above river-bed. This is on the right bank, and consists of three 58-inch balanced "Ensign" valves of the same type as described on the Bellefourche dam (see photo A, plate 18). Each discharges into separate tunnels, which meet after some distance and continue as one tunnel of 9 feet diameter through the rock, discharging over a weir at the mouth of the tunnel and over the rocky cliff on the right bank. The tunnels are lined with cast-iron which has become deeply pitted. Another outlet for power purpose was provided at 65 feet above the river bed. This consists of a 10-foot diameter steel pipe at a slope through the dam. This is controlled by an enclosed ring-valve near the down-stream end. In addition to the above, a 7-foot diameter tunnel passes through the rock on the left bank to convey the water from the end of the high-level furrow to the power-house. At the intake to this tunnel are settling basins and scouring sluices (visible in photo C, plate 16) and a rotary screen for removing débris.

Electric Power. The power-house is built into the rock on the left bank immediately below the dam. Provision is made for six turbines, three to work from the high-level canal and three from the dam. The former, and two of the latter, have been erected. They are vertical-axis turbines, direct-connected to dynamos above. The former have water bearings, but the latter have roller bearings which are found to be more satisfactory. The power of each is 1200 to 2000 kilowatts. They operate at 500 r.p.m., and produce 3-phase, 25-cycle, 2300-volt current. The transformer-house is lower down the stream, and the current is here

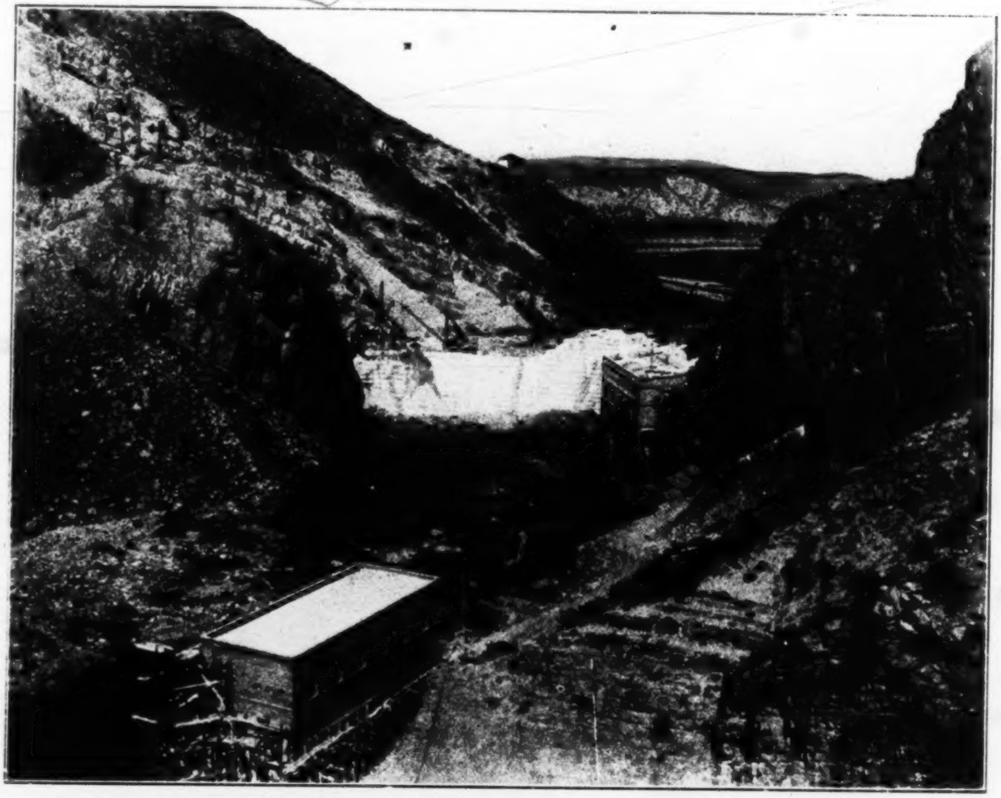
SALT RIVER SCHEME—Roosevelt Dam.



(*a*) Three "Ensign" Valves near right bank.

Plate 18.

SALT RIVER SCHEME.



(*b*) Roosevelt Dam during construction—looking up-stream.

(*c*) Granite Reef Weir during construction—from right bank.

raised to 45,000 volts and sent down to the valley, Phoenix being sixty-five miles off. The transmission-line is supported on high steel towers, originally at intervals of 120 yards, and with insulators upwards. Recently the towers have been brought closer together, and the insulators have been replaced by the hanging type.

The high-level furrow passes round the reservoir for 19 miles through fairly difficult country. It has a capacity of 225 cusecs, and, together with its diversion-weir, cost nearly 1½ million dollars.

Granite Reef Weir.

The water passing Roosevelt dam is measured over an overflow weir and then runs down the 45 miles of gorge to the Granite Reef weir which also catches the water from the Verde River. This weir is 1000 feet long, and has a maximum height above original river-bed of 18 feet. A granite foundation was found for only part of the length. Where rock was easily reached, the peculiar section shown at top of lower right corner of fig. 50 was adopted, the weir resting like a bridge on piers with cut-off wall on up-stream side. Where rock could not be easily reached, the section at bottom of fig. 50 was adopted, the cut-off walls being carried to compact sand, gravel, and boulders. The concrete apron was laid in squares of about 10 feet with open joints. The pond above the weir has now been practically silted up (the Verde River being heavily charged), and open flow is maintained in front of the canal-intakes by scouring channels and sluices as at the Laguna weir.

Canals.

The Arizona canal on the right bank has a capacity of 2000 cusecs, and the main canal on the left 1600 cusecs. Drops in the larger canals are utilized for power purposes. Two of these are where water is dropped to the older canals which formerly had intakes lower down the river. One (No. 3) on the cross-cut canal was in course of construction during my visit, and another (No. 4) is completed at a drop on the Arizona canal. An interesting feature of this plant is the syphon-spillway, which automatically keeps a constant head above the plant.

Pumping.

The large amount of power available on this scheme is utilized extensively for pumping water from underground supplies for quite a large area. These pumps serve the double purpose of keeping down the water-plain and irrigating high-lying patches of land. There are nine of these in operation, each pumping about 10 cusecs. The underlying formation is gravel and sand charged with water. A 16-inch California casing is sunk, as described on the Redlands scheme, to a depth of about 200 feet. Around this a concrete caisson of 9-foot diameter is sunk, the water being removed during excavation by a 12-cusec pump and sinking of the caisson being stopped when the pump fails to keep the pit dry, which is found to be roughly at about 50 feet. A permanent centrifugal pump is then placed at the bottom of the caisson with axis vertical and driven by a motor at the top.

The power is also used to operate a pump which raises water 40 feet from a furrow for irrigating the high slopes at the foot of the Salt River Mountains. Considerable seepage water returns to the river, and at the Joint-head dam 45-60 cusecs are picked up when no water is passing over Granite Reef weir.

Soil, Slopes, and Method of Irrigating.

The soil is generally a sandy loam, and a hard-pan layer is frequently found from 2 feet to 9 feet below the surface. Sand and gravel underly a large area. In the flatter areas a more compact soil is found. The surface slope over the greater part of the area is between 10 feet and 20 feet per mile. The flattest land is in the neighbourhood of the neck between the Salt River Mountains and the towns of Mesa and Chandler, where the slope is about 5 feet per mile. Steeper slopes up to 100 feet per mile are obtained under the pump-line round the foot of the Salt River Mountains. The water-table has risen and seepage and alkali have appeared in the flatter lands in the neighbourhood of the neck, where I noticed several lucerne fields abandoned and overgrown with salt-bush or partly spoilt by bare alkali patches. Several of the well-pumps operated by motors are situated in this area, and they serve to reduce the water-table. No other drainage works have yet been constructed.

For lucerne and cereals the general method of irrigation is by surface-flow between borders, the slope being usually very suitable for this. In many places I noticed that the long borders were constructed only to a point some distance from the cross borders at the bottom of the beds, so that any bed which brought a surplus of water to the bottom could spread it out on the bottom of neighbouring beds. Where the soil is the typical sandy loam and the slope is about 20 feet per mile the beds are usually about 300 yards long and 50 feet wide, and about 200 yards long on sandy soil. On the flatter and more compact lands near the neck the beds are usually 400 yards long and about 40 feet wide. The usual irrigating stream is from 1 to 3 cusecs. Recent experiments tend to show that less water is required and more even wetting is obtained with the larger stream, say 2½ cusecs, and shorter beds, say 100 yards.

Crops.

The total area cultivated in 1912 was 159,000 acres, including 30,500 acres under private canal systems. Lucerne occupied nearly

50 per cent. of the area, and cereals—chiefly barley—about 30 per cent. About 12 per cent. was irrigated pasture of natural grasses, such as Bermuda grass (*Cynodon dactylon*). The remaining area was given to sugar beets, vegetables, fruit (melons, citrus, and olives), kaffir corn, milo maize, sorghum, and cotton, the latter increasing rapidly in area. Lucerne gives an average return of 5 tons from five cuttings. As on the Imperial Valley scheme, during the hottest months of July and August the growth of lucerne seems to be retarded, and many irrigators do not apply water during these months. Lucerne is sold at about $12 per ton baled, but is largely fed to stock. Ostriches are more abundant here than in any other part of America. A census taken by the United States Reclamation Department shortly before my visit gave the total on this scheme as 4119, valued at $540,000, or $131 each. I visited several ostrich farms (for result see *South African Agricultural Journal*, March, 1914, p. 424) and found the quality of feathers poor, but still it was claimed that a return of $15 per bird was obtained. On one farm four birds were running to 1 acre, but usually they are run more closely and are hand-fed.

Settlement and Cost.

The history of this scheme is interesting, as it illustrates, like the Boise scheme, the work of the Reclamation Department in perfecting the irrigation of an area already highly developed, as contrasted with the usual work of reclaiming previously unirrigated ground. The following is extracted from the ninth annual report of the Reclamation Service:—

> Scattered throughout the Salt River Valley are remains of numerous canals and irrigation works, giving evidence that the country was inhabited in earlier times by people versed in the practice of irrigation. The lines of at least eleven of the old main canals, aggregating about 135 miles in length, and which must have watered more than 100,000 acres of land, have been traced.
>
> Modern irrigation in the Salt River Valley dates from the beginning of construction, in 1867, of what was known as the Swilling ditch and its distributing system. A part of this system was later known as the Maricopa canal, another part as the Salt River Valley canal, and the first mile and a half of the original main canal as the Joint-head canal. From 1870 to 1894 various other canals were built, the principal canals on the north side of the river being the Grand canal, the Arizona canal, and the Crosscut canal connecting these two. Some of the principal canals constructed on the south side of the river were the Tempe canal, the Utah canal, and the Consolidated canal.
>
> The diversion for the Arizona canal was made by means of a timber-crib rock-filled dam covered with heavy planking. The other dams on the river were temporary affairs of brush and rock, that were usually swept away more or less completely by the periodic floods that occur in the river with great regularity. After the floods these dams could not be repaired until the river had reached a comparatively low stage, with little water available for irrigation, and as a result the valley was generally in a state of water famine.
>
> In about 1884 or 1885 it became evident that the development of agriculture in the valley had reached the point where the low-water flow of the river was insufficient for satisfactorily

watering the lands then in cultivation, and it was realized that storage reservoirs were desirable, so that the flood waters might be utilized. During the period from 1890 to 1899 the shortage of water was very pronounced and some of the cultivated land reverted to desert.

In 1900 the citizens of Phœnix organized a water storage committee for "promoting investigations and developing some project for the storage of water," and requested the Department of the Interior to undertake the investigation of the feasibility of storing water for the use and benefit of the existing canal systems in the Salt River Valley.

This was previous to the formation of the Reclamation Department in 1902. The scheme was worked up by Government and approved in 1903, and, after terms of contracts had been settled with an association of those who were to benefit by the water, arrangements were soon made for construction. Most of the irrigators entered into contracts with Government for the use of stored water, those who stood out being chiefly owners of land under the older canals, such as the Tempe, as they had a prior right to the ordinary flow, which was usually sufficient at all times without storage. As water-rights are attached to each parcel of land irrigated, and do not belong to the company constructing or owning the canal. Government considered it necessary to have the rights of each parcel of land defined by Court in quantity and order of priority. As there were some 5000 separate owners the collection of evidence took about 2½ years, and a judgment was given in 1910 which is well worth reading as illustrating the application of the law of priority of appropriation. The amount was fixed with a duty of 1 cusec to each 133 acres measured at the field, and if measured at the intake 1 per cent. to be added for each mile from the intake. Early rights were in this way established over 151,000 acres, which were proved to have been in continuous cultivation prior to the case. A further 29,000 acres which were once irrigated but subsequently abandoned were given rights later than those of the former lands, but prior to any rights of lands which might subsequently be irrigated. The Government further bought out practically all the old canal companies, and now supplies water on a uniform basis to all in the system, but is obliged to pass as much of the natural flow as the older canals not in the scheme (e.g. the Tempe) are entitled to.

The judgment fixing priorities does not therefore seem to have much effect among those who have made contracts with Government, as they pay for all water used on a uniform basis, even when the ordinary flow without storage would be sufficient to supply them according to their priorities. It might be expected that those higher on the list of priorities would obtain preferential treatment. The arrangements with the water-users are somewhat similar to those described on the Boise scheme. No building charge is made and water is supplied on a rental basis. In 1912 the charge was 60 cents per acre-foot supplied during four months in summer (1st June-30th September), and $1 per acre-foot supplied during the remaining eight months (1st October-31st May). With a view to encourage economy in the use of water the following rates are now proposed:—

$1.10 for 2 acre-feet (minimum charge whether used or not).
.40 for third acre-foot.
.50 for fourth acre-foot.
.60 for all additional acre-feet used.

The above rates apparently include annual cost of operation and maintenance, which was actually $1.67 per acre irrigated in 1912.

In 1912 the area irrigated in the scheme (apart from private canals) was 127,700 acres, and the average application measured at the diversion-weir was nearly 6 feet, and measured at the fields about 4 feet. The proportion used during the eight months at $1 is about 60 per cent., and the average rental payment would therefore be about $3⅓ per acre. The whole area proposed to be irrigated is 230,000 acres, of which 40,000 acres are under pumping schemes.

It is doubtful whether the water supply is sufficient for all this area, and a commission has recently been appointed by Government to determine exactly what limit will be put to the area capable of irrigation. The whole cost to date, including purchase of old canal systems, is about ten million dollars. The area under rental contracts is 160,000 acres. The average size of farm is 42 acres, though over half of the settlers own less than 20 acres. Twenty-five ditch-riders attend to the distribution of water under superintendents.

CHAPTER XVI

THE RIO GRANDE SCHEME

(*United States Reclamation Service, New Mexico*)

THE Salt River scheme was the last which I investigated on the western side of the great divide. The Rio Grande River drains the eastern side of the great mountain axis and discharges into the Gulf of Mexico. The river in its lower reaches is the boundary between Mexico and

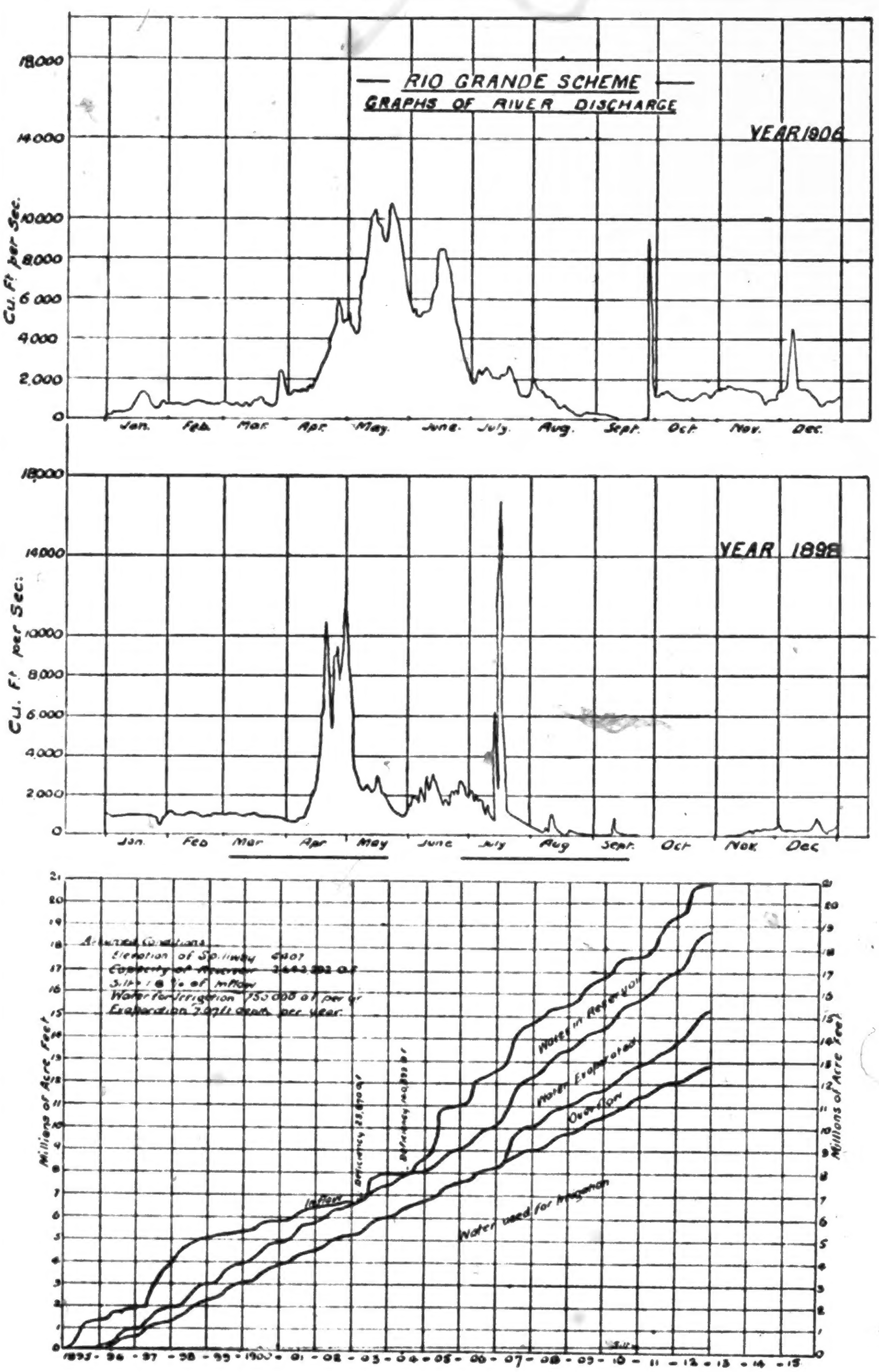


DIAGRAM SHOWING PROBABLE ACTION OF RESERVOIR IF CONSTRUCTED IN 1905.

Fig. 52.

the United States, and as the former country has irrigable lands along the right bank international treaties have been necessary to regulate the use in America. The Rio Grande, like our Orange River, has cut a deep channel considerably lower than the surrounding country, and the irrigable lands extend as long narrow strips along the valley, seldom reaching a width as great as five miles. Thus the whole area of 180,000 acres embraced in the scheme is spread along the river for a distance of 160 miles.

The average elevation of the irrigable lands is 3700 feet, the range of temperature 0° to 100° F., and the rainfall over the irrigable area 9½ inches (chiefly in mid-summer), about one-third of the whole falling in July and August. This is the only scheme of those I investigated which has its chief rainfall in summer, and in this and other climatic features the conditions are somewhat similar to the Karroo and the eastern part of the Cape Province. The annual evaporation is about 7 feet per year.

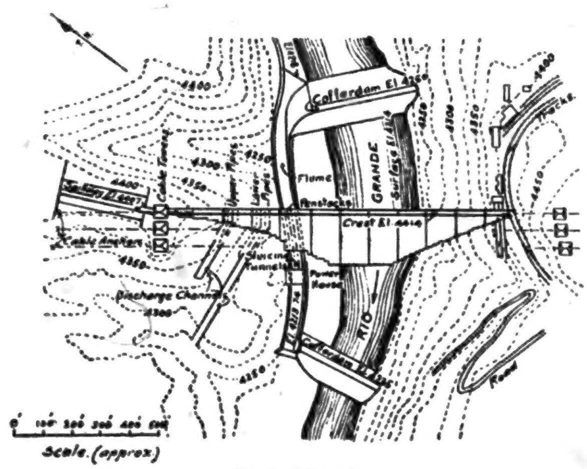
Water Supply.

The drainage area above the storage dam is 37,000 square miles. The maximum run-off is 2,420,000 acre-feet, the minimum 201,000, and the mean for sixteen years 1,150,000 acre-feet. Part of the flow, especially from the high mountains in the north, is derived from melting snows which produce regular floods in April, May, and June, but this water is largely used by schemes higher up. At times the flow dwindles to practically nothing and after heavy rains has risen to over 30,000 cusecs. Under these conditions the graph of flow for each year shows great differences. In fig. 52 are given two graphs (for 1898 and 1906), and also a diagram showing how the reservoir would have acted if constructed in 1895.

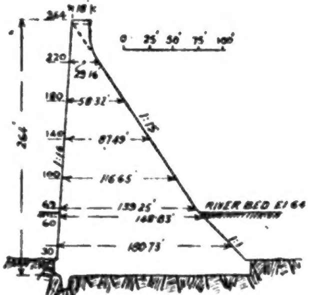
The water, like that of the Colorado ond our South African rivers, is usually coloured by silt, and this has to be taken into account in estimating the storage of the reservoir, an allowance for silt being made of 1.8 per cent. of the inflow.

Outline of Scheme.

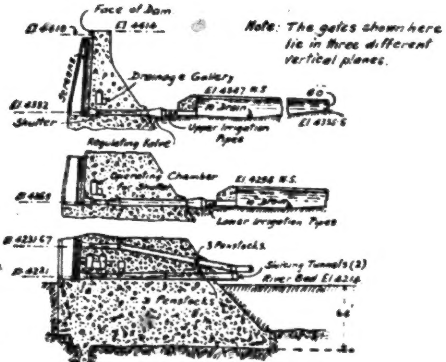
The chief work on this scheme is the Elephante Butte Storage Reservoir which is now in course of construction. Several pick-up weirs and canals are provided for to irrigate 180,000 acres stretching for 160 miles down from the storage dam, less than half of which is at present irrigated. By treaty with the Mexican Government 60,000 acre-feet of the storage must be passed annually over the border for the irrigation of 25,000 acres in Mexico.


Cofferdam El. 4250
Flume
Penstocks
GRANDE
Crest El. 4414
Cable Anchors
Sluicing Tunnels
Power House
Discharge Channel
RIO
Road
Tracks
Scale (approx.)

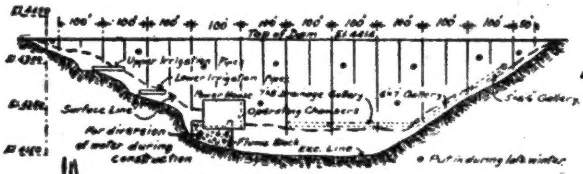
PLAN OF DAM.


0 25' 50' 75' 100'
264
220
180
140
100
62
60
30
29.16
58.32
87.49
116.65
139.25
148.83
180.73
RIVER BED EL. 64

CROSS SECTION.

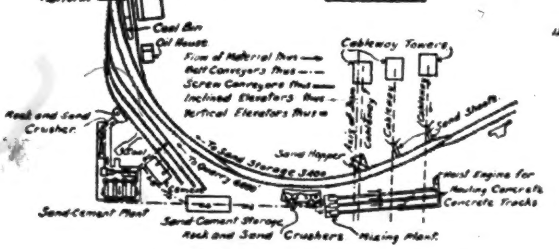

Face of Dam El. 4414
Note: The gates shown here lie in three different vertical planes.
Drainage Gallery
Shutter
Regulating Valve
Upper Irrigation Pipes
Operating Chamber
Lower Irrigation Pipes
3 Penstocks
Sluicing Tunnels (3)
River Bed El. 4216

CROSS SECTION SHOWING ARRANGEMENT OF GATES


Top of Dam El. 4414
Upper Irrigating Pipes
Lower Irrigation Pipes
7×8 Drainage Gallery
6×7 Gallery
5×6 Gallery
Power House
Operating Chambers
Surface Line
For diversion of water during Construction
Flume Block
Exc. Line
Put in during last winter

ELEVATION OF DAM, LOOKING UPSTREAM, SHOWING EXPANSION JOINTS.

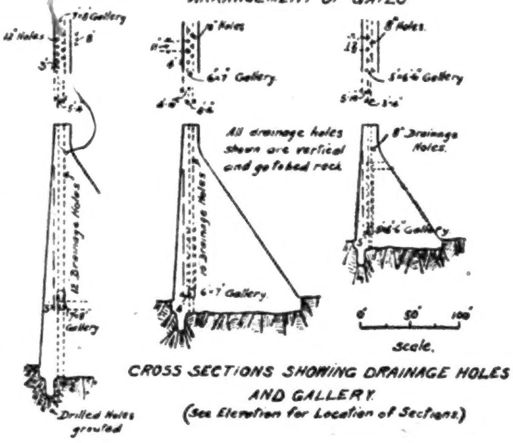
0 100' 200' 300'


Platform
Store House.
Coal Bin
Oil House
Flow of Material thus
Belt Conveyors thus
Screw Conveyors thus
Inclined Elevators thus
Vertical Elevators thus
Cableway Towers
Rock and Sand Crusher.
Sand Hopper
Sand Storage
Hoist Engine for Hauling Concrete
Concrete Tracks
Sand-Cement Plant
Sand-Cement Storage
Rock and Sand Crushers
Mixing Plant.

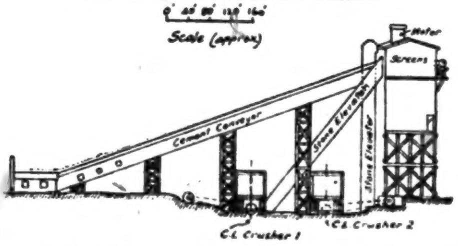
PLAN OF CONSTRUCTION PLANT

0 40 80 120 160

Scale (approx.)


7×8 Gallery
12" Holes
8" Holes
6×7 Gallery
5×6 Gallery
All drainage holes shown are vertical and go to bed rock.
8" Drainage Holes.
12" Drainage Holes
10" Drainage Holes
Drilled Holes grouted
0 50' 100'
Scale.

CROSS SECTIONS SHOWING DRAINAGE HOLES AND GALLERY.
(See Elevation for Location of Sections.)


Motor
Screens
Cement Conveyor
Stone Elevator
C.L. Crusher 1
C.L. Crusher 2

ELEVATION OF CONVEYOR AND ELEVATORS SERVING MIXING PLANT.

RIO GRANDE PROJECT.

ELEPHANT BUTTE DAM.

Fig. 53.

THE ELEPHANTE BUTTE DAM.

Design. This dam is now being built across the Rio Grande River. It will have a maximum height of 264 feet above the foundations and 200 feet above the river bed. The storage will be 2,600,000 acre-feet, and the stored water will stretch back 40 miles and flood 41,000 acres. Although this dam is not nearly so high as the Arrowrock dam, it requires the same volume of masonry (about 500,000 cubic yards) on account of its greater length. The length of the crest will be 400 yards, and consequently the dam is being built in a straight line, and not curved like the high masonry dams previously described.

The foundation rock is not nearly so satisfactory as that of the dams previously described. The Shoshone and Arrowrock dams were built on sound granite, the La Grange and Roosevelt dams on a compact quartzite. Here, however, the formation of the surrounding country consists of layers of sandstone, quartzite, shale, and dolerite, all considerably folded. On the line of the dam the strata dip steeply upstream. On the bottom fairly hard and compact rock has been found, but on the right bank the strata appear to be very soft, and trial tunnels were being driven for long distances to locate sound hard rock. On account of the inferior foundations the section of the wall is heavier than that of Arrowrock, especially on the down-stream side below bed-level. Greater provision is made for drainage, and, in excavating the cut-off trench, as an extra precaution to avoid disturbing the strata, "channelers" are used to separate the rock before blasting.

In considering the design of the section it should be noted that the future raising of the crest by 40 feet has been kept in mind, because silt will gradually reduce the capacity.

Contraction-joints are provided as shown on the elevation (fig. 53), gaps along the length of the dam being left during summer and filled up in midwinter, as in the Arrowrock dam. The grouted holes below the cut-off trench and the vertical drainage holes are also somewhat similar to those of Arrowrock, and their position is shown on the sections.

All outlets are to be on the right bank. They are at four levels, the upper two sets discharging into channels through a projecting nose of rock, and the lower two (one for power) discharging into the flume built for diversion of the river during construction. Each of the lower gates has a separate tunnel 60 inches × 47 inches. The gates in the two sluicing tunnels and in the six penstock tunnels are identical and are of the ordinary vertical sliding cast-iron type, each operated by a hydraulic ram from a chamber immediately above the gate. The two sluicing tunnels are each provided with duplicate gates—one about 15 feet behind the other. The two upper sets of gates appear also to have sliding valves near the up-stream face, and regulating valves, probably of the enclosed ring or balanced type, on the down-stream face, but I have no details of these.

The spillway, 300 feet long, is in a saddle on the right bank, and its crest is 7 feet below the crest of the dam.

Materials.

A sand-cement plant similar to that at Arrowrock is erected, and the mixture is used with greater economy even than at Arrowrock on account of the greater cost of cement and cheaper labour. A local sandstone is crushed for sand and mixed with an equal quantity of cement. The following is an analysis of the cost of one barrel of the mixture:—

Half-barrel portland cement @ $2.50	$1.250
Sandstone	.035
Plant charge	.092
Labour	.068
Supplies	.055
Power	.184
Cost of one barrel of mixture	$1.684
Net saving per barrel by using mixture	$0.816

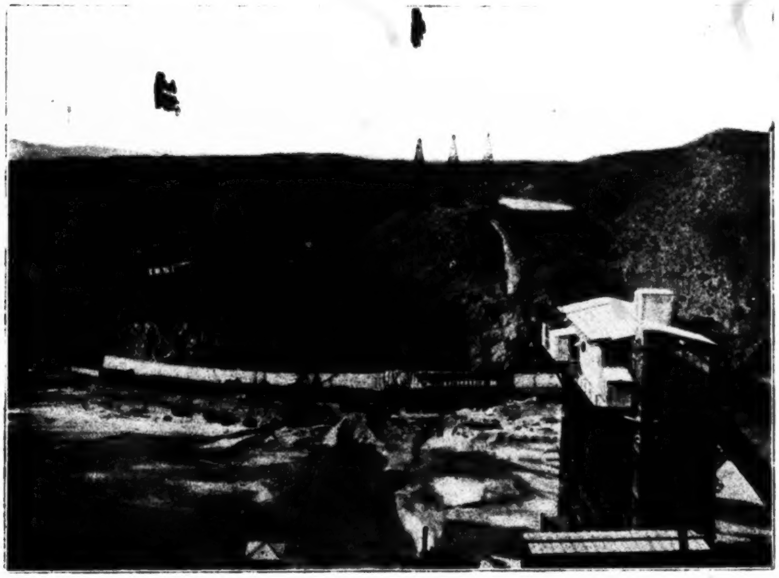
And over 500,000 barrels will be used in the work.

The bulk of the concrete is mixed in the ratio of 1 : 3 : 6, and plums of large and small rock are placed in it. The stone quarries are a couple of miles off, and the stone is brought to the site by rail.

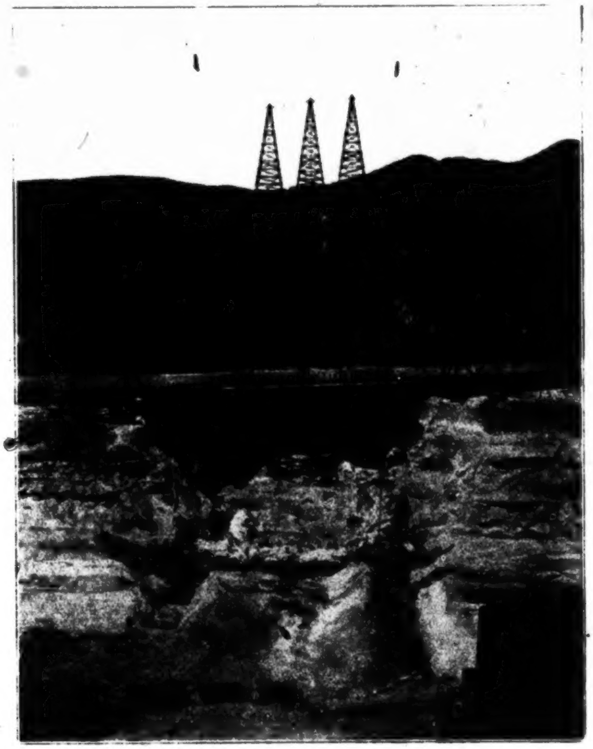
Methods of Construction and Plant.

Hydraulic power is not available as at Arrowrock and Lahontan dams, and the power for all operations is generated by a 2000-horsepower steam-turbine plant driving dynamos. This power is used for lighting up the works and the railways to the quarries at night (work being carried on at night), for driving the sand-cement, rock-crushing, air-compressing, concrete-mixing, pumping, overhead haulage, conveyors, and other plants. Three overhead cableways cross the river with a span of from 1416 to 1436 feet. They are Lidgerwood cables exactly like those at Arrowrock, each operated by a 300-horsepower motor on

RIO GRANDE SCHEME—Elephante Butte Dam.



(*a*) From left bank. Diversion-flume on right of river. Concrete-mixing plant in foreground.

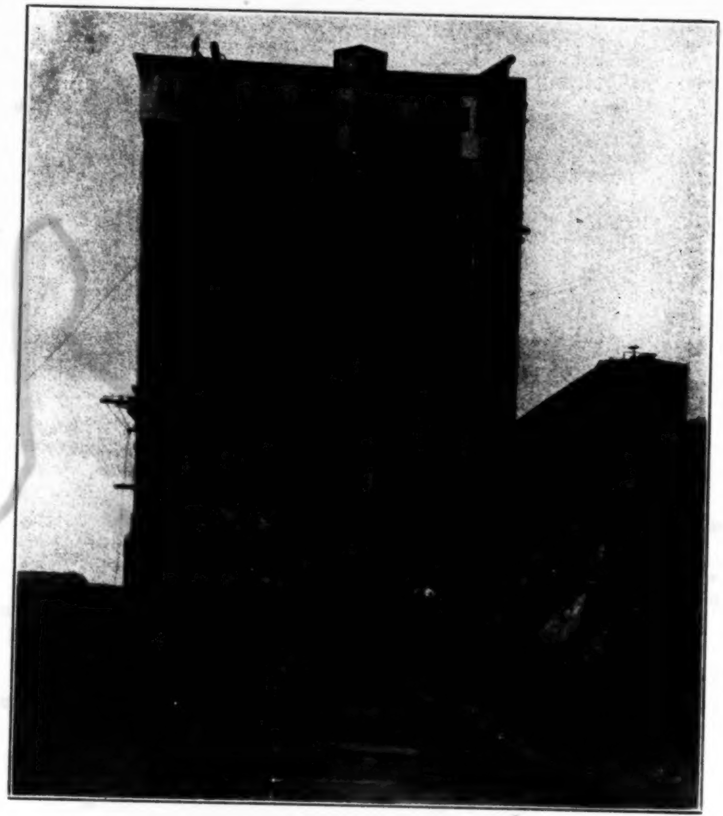


(*b*) Excavation of sand and gravel.

Plate 19.

RIO GRANDE SCHEME—Elephante Butte Dam.

(c) Dam-site—looking up-stream.



(d) Concrete-mixing Plant.

the left bank, employing alternating current (3-phase, 60-cycle, 2200-volt) and designed for loads of 10 to 15 tons. Most of the plant is on the left bank on a ledge at about the level of full-supply, and the general lay-out is shown in fig. 53. The mixing plant is just up-stream of the upper cable, and consists of three 80 cubic feet Milwaukee mixers. These discharge the concrete into skips on trucks which run on rails on a short platform under the three cableways, each of which can pick up the skip and carry the concrete to the work. The measuring hoppers, screens, and water-tank are all above the mixers in the same building, the mixing being controlled by ingenious levers which make most of the operations almost automatic.

The sand-cement is raised from the storage-house to the bins at the top of the building by an enclosed inclined belt-conveyor (Stephens-Adamson). The sand and stone are also raised to the screens from pits close to the mixer by inclined and vertical bucket-ladder elevators. Immediately over the pits are gyratory crushers which crush the rock. The rock and sand are supplied to these by inclined shoots, fed by side-tipping from the railway which runs alongside at a higher elevation. This railway passes under the cableways, which also supply sand and stone from the excavation in the bed of the river. The sand and gravel in the bed are drawn under the cables by dragline excavators working on endless ropes in the bed. Plums are handled by derricks on the dam.

An interesting machine called a "Channeler" (Sullivan Machinery Co., Chicago) is used for excavating the cut-off trench without shattering or opening up the foundation rock by blasting. It is like an enormous vertical drilling-machine. It is mounted on rails and travels along the line of the cut-off wall, separating from the sides the central wall of rock, which can then easily be removed without disturbing the surrounding strata. Similar machines were used on the Panama Canal for cutting trenches under locks on similar foundations.

For diverting the river during construction a concrete flume 40 feet × 14 feet was constructed on the right bank and carried down to solid foundation so that it can be built into the dam. The sluicing and power channels will discharge into it eventually.

The whole work is being done by Government, and not by contractors.

Lands, etc.

It is too early to give figures of cost or settlement, and I did not visit the lands irrigated. The total area under the scheme is

180,000 acres, 25,000 acres in Mexico and 155,000 acres in the States, nearly all of which is already in private ownership, but less than half under existing irrigation schemes. The agricultural conditions appear to be somewhat similar to those of the Salt River scheme, and lucerne will probably occupy half of the area. As indicating the monthly demand for water, the following table is extracted from the agreement between Mexico and the United States, limiting the monthly rate at which water is to be released for Mexico from Elephante Butte dam:—

Month	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Percentage of whole volume (approx.)	0	2	9	20	20	20	14	7	5	2	1	0

CHAPTER XVII

SETTLEMENT

How the Federal and State Governments Help.

1. Settlement under the Reclamation Act.

THE original Reclamation Act of 1902 and the important amendments and additions since then are given in Appendix A to this Chapter. Before dealing with this it is necessary to explain what is meant by "entry of land" and "entry under the homestead laws," as these expressions occur in the Act.

The two principal ways of acquiring land from Government in America are by homestead entry and by desert-land entry. Except in a very few instances Government does not sell land. Nearly all public land that is not already taken up or reserved for forests, minerals, or other purposes is open to entry by one or other of the above methods. Naturally most of the land in the East, and the more favourably situated land in the West, is already taken up, but there are still huge areas unoccupied.

Desert-land Entry.

Under the "desert-land entry" any citizen of the United States over twenty-one years of age can settle on unoccupied desert land up to a maximum area of 320 acres, and, if he proves that he has brought water on to it and cultivated one-eighth of the area and expended $3 per acre within four years, he obtains possession on paying $1.25 per acre to Government. Desert lands are defined as those which without irrigation will not produce a crop, and lands bordering streams are excluded.

As we shall see, under section 3 of the Reclamation Act no desert-land entries are allowed on areas included in proposed Federal Reclamation schemes after notice of the scheme has been given. If a desert-land entry was made on such land previous to the notice, then the entryman cannot retain more than 160 acres. An example of desert-land entry will be found on the Imperial Valley scheme.

Homestead Entry.

Homestead entry is the usual method of taking up better lands; it is the chief method of entering public lands embraced in the Reclamation schemes, and the only method after such lands have been publicly withdrawn from other forms of entry under section 3 of the Reclamation Act.

There are no limitations as to the nature of homestead lands such as apply to the desert-land entry. Any unoccupied public lands can be entered except those reserved for forests, minerals, etc. The limit as to area is 160 acres (enlarged in 1912 to 320 acres on non-irrigable ground). Any citizen of the United States who is over twenty-one years of age, and who does not already own 160 acres, can make a homestead-entry filing. Within six months after filing he must establish residence on the land, and he must remain in continuous residence for five years (recently altered to three years) for seven months of each year. He must cultivate a reasonable proportion of the land (recently fixed as—during the second year one-sixteenth, and during the third year one-eighth of the whole area), and he must have a proper house built on it. If he fulfils these conditions and makes the necessary payments within seven years (recently five) he can obtain title. The payments vary slightly, but $1.25 is usually charged per acre, and in addition filing fees amount to a total (for 160 acres) of $16 at entry and $6 at final proof of title. In this liberal way the Government obtains settlement and development of its unoccupied lands and receives about $1.25 for every acre disposed of.

The Reclamation Act.

The next step was to devote the money received in this way to the development by means of irrigation of large areas which would otherwise not be taken up by homesteaders. This policy was sanctioned by the Federal Government in the Reclamation Act of 1902. Since that date the development of such works has been extraordinarily rapid, and most of the works I inspected were carried out by the Reclamation Service. The history of the Reclamation Act and its modifications is very instructive as showing what unexpected difficulties have to be encountered in such work. The provisions of the original Act of 1902 were roughly as follows:—

(1) The funds for such work are all sums obtained from the disposal of public lands by homestead entry or otherwise.

(2) The Reclamation Department investigates likely schemes, and reports cost, area etc., to Government, whose approval is necessary.

(3) On approval by Government all public lands to be served by the scheme are withdrawn from entry by all other methods than homestead entry, and such entries are thereafter on condition that all charges which will be made for the works must be paid by the entryman, and Government fixes the limits to the area that can be entered as between 40 and 160 acres.

(4) Construction is then commenced, and as each unit is completed public notice is given stating the limiting farm-area and the charges to be made per acre to cover the cost of construction, payable in ten annual instalments without interest.

(5) An entryman is subject to the homestead laws, but he must cultivate a larger area (half of whole) and make all payments due before he can obtain title. Failure to make two annual payments is cause for cancellation of entry.

Private owners of land falling in the area of the proposed scheme may obtain water-rights on similar conditions of payment, but not for a larger area than 160 acres.

(6) When the payments for the major portion of the lands are made, then the management and operation shall be handed over to the owners to be run under methods approved by Government, but reservoirs will remain under Government control.

(7) All such works are liable, like any other private works, to the ordinary Federal and State water laws.

Modification found necessary.

Shortly after the passage of this Act in 1902 a number of schemes were started in various parts of the West. Slight additions and modifications were made in 1906, which provided for town sites and reduced the minimum area for occupation from 40 acres to 10 acres; but the most important modifications were made in 1910 after the Act had been in operation eight years. The chief lessons learnt in this period were that settlers are not attracted to these schemes as rapidly as was expected, and that difficulty is experienced in getting in the full payments from a large proportion of the settlers.

These lessons are important, as similar conditions are likely to be found in South Africa. It is probable that the strict conditions of residence necessary to exclude purely speculative entries account in part for the slowness of entry. The average American, like a large proportion of South Africans, does not care to be tied down by rigid conditions of residence, and likes to see some possibility of parting with his holding at a profit within a short time. It is no doubt very wise to exclude this speculative element, even if it results in slower settlement, but all the consequences of a slow rate of settlement must be allowed for, especially in estimating the expenditure and revenue and the capacity of canals, etc. The difficulty of getting in payments, especially during the first few years, has on several schemes been found to be very great, and it is important to discover the cause and remedy. The chief causes are probably the lack of experience and of capital among the entrymen. Both of these conditions are likely to be found in South Africa. It is gradually being realized that irrigation is a highly scientific form of intensive cultivation, and lack of experience is likely to lead to needless waste of capital and to poor returns, especially at the outset. The average entryman seldom has sufficient capital for the proper development of the area he takes up. One reason is that he usually takes up an area greater than his means will enable him to develop sufficiently to pay the charges on the whole area. An entryman has a natural tendency to over-estimate what he can accomplish in the hope of greater profit, but the evil consequences are so great that in later schemes the maximum area of entry allowed has been reduced to 80 or even 40 acres, and warnings are issued on some of the schemes (see Truckee-Carson scheme) against entry without sufficient capital.

In consequence of these lessons, learnt as the result of eight years' experience of the Reclamation Act, certain alterations were made in the Act in 1910. Slowness in settlement and repayments, and in several cases under-estimates of cost, had caused serious financial difficulties. Anticipating that there would be a rush of settlers to the numerous schemes started after 1902, and that repayments would be made regularly, it was naturally expected that the money available for reclamation, as provided under section 1, would be regularly returned and could be used over and over again on other works. We have seen that these expectations were not fulfilled, and in 1910 Government had to provide for lending to the Reclamation Department a sum up to twenty million dollars (apart from sources provided under section 1) in order to complete and maintain works already sanctioned and under construction. And in 1911, to make it easier for settlers in the first few years (and also to raise under-estimated charges per acre), provision was made for altering previously published charges per acre, and, instead of equal annual instalments, a graduated system was introduced with very low charges in the first few years. At the time of my visit a further relief was being considered by spreading the repayment over twenty years instead of ten, and it is likely that this will shortly be made law. This will be a very generous concession, as no interest is charged to the settlers. It is worthy of note that Government has not yet adopted the policy of loan advances (in cash or stock) to settlers to help them over the first few years.

Other changes made in 1910 allowed a settler to transfer his holding after five years, if the conditions of residence and cultivation were fulfilled, and provision was made for withdrawing land even from homestead entry until the works were sufficiently advanced, as it was found that after the inception of a scheme a number of the settlers who had taken up land suffered hardships before the works were sufficiently completed to supply water.

The most important recent addition to the Act was the "Warren Act" in 1911, which extended the scope of the work of the Reclamation Department to the perfection of the irrigation of areas already highly developed. The Warren Act allowed contracts to be made with owners of other works on a rental basis instead of (as provided in section 4 of the original Act) ten annual repayments of building charges. Such work chiefly takes the form of expensive storage reservoirs, and examples of this are to be found in the Boise and Salt River schemes. This class of work is interetsing, as similar work may be required of Government in South Africa in areas, such as Oudtshoorn, where irrigation is already far advanced and large storage reservoirs are necessary for more extensive and more profitable use of the whole flow of a river.

Results achieved.

The results achieved in the ten years from 1902 to 1912 are roughly as follows:—Twenty-eight schemes have been initiated. The estimated total area to be irrigated by these schemes on completion is about three million acres, and the estimated cost about $120,000,000. Actually the net expenditure in the ten years was $72,000,000, and the works were completed so far as to be able to irrigate about 17,000 farms, totalling 1,170,000 acres. Of this area about half is actually irrigated, though about three-quarters is under contract to take water. Of the latter area a large portion was previously irrigated by private works (as we have seen on the Boise and Salt River schemes) and is now supplied under the rental-contract system, instead of by the system proposed in the original Act of paying off the building charges by instalments. We thus see that of the three million acres to be irrigated only a little over half a million acres were actually irrigated in 1912. These results all confirm what was previously pointed out, namely, that extremely rapid development and settlement must not be expected, and a considerable time must be allowed for the whole contemplated area to become fully developed and settled. How long it will take to achieve this remains to be seen.

The estimated cost of developing the whole area works out at roughly $40 per acre, which is higher than most of the older private schemes. It should be pointed out, however, that the older development naturally followed the easier lines, and the Reclamation Department—coming comparatively late into the field of development—had to take up the more difficult and expensive schemes, often requiring storage or pumping. Moreover, in thoroughness of construction and reliability of figures as to water supply, area, and cost, the Reclamation schemes generally surpass the private schemes. The distribution system of furrows, for example, is constructed in far more detail under the reclamation schemes, and usually brings the water to the edge of each settler's farm, whereas most private schemes leave the minor distributaries to be constructed by the settlers. In Federal schemes the area to be irrigated and given out to settlement is always carefully kept within the limits of the available water supply, whereas failure to do this has led to disastrous results in many private schemes. The Federal method of accounting is acknowledged as one of the most perfect in America, and by proper allocation of every item of expenditure throughout the service allows of a complete study of cost from any point of view.

The Federal organization of maintenance and operation is also very thorough and sympathetic. All the schemes are still run by the Reclamation Department, and none have yet been handed over to the settlers, as provided in section 6 of the Act of 1902. On some of the schemes the settlers are urging the Government to hand over the management, but it is doubtful if this would result in any ultimate economy, as the settlers have not the wide experience and business organization of the Reclamation Department, and can never have a system so free from suspicion of partiality.

2. Settlement under the Carey Act and other Methods of Irrigation Settlement.

While, under the Reclamation Act, the Federal Government both provides the land and carries out the work, under the Carey Act it provides only the land on condition that private capital shall construct the works. In this way, without expending any public money, the Government secures the settlement of vast areas which would not ordinarily be occupied under homestead entry. The area of land embraced in schemes under this Act actually exceeds the area proposed under the Reclamation Act, and this method of turning the private capital of a country to the successful development and settlement of the land is well worth studying. The original Act was passed in 1894, or eight years before the Reclamation Act, but very little development took place during these eight years owing to conditions in the original Act which discouraged investors. These defects in the Act were finally remedied in 1902, and thereafter development under this Act was extremely rapid. Practically, then, the revised Carey Act and the Reclamation Act started in the same year, 1902.

Provision of Carey Act.

The original Act and the three chief amendments are given in Appendix B to this Chapter. The substance of these is as follows:—

Any State in which are public desert lands may submit to the Federal Government plans for irrigation works to reclaim portions of these desert lands. If these plans are approved as being "sufficient to thoroughly irrigate and reclaim the said land," the Federal Government will reserve these lands for that purpose, and on completion of the works within ten to fifteen years will hand over the lands to the State free of cost.

The maximum total area to be granted in this way to any one State was fixed as one million acres, but in two States (Idaho and

Wyoming) development was so rapid and successful under this Act that the maximum was raised to three million acres for Idaho and two million for Wyoming.

As in the Reclamation Act, the maximum individual holding is limited—in this case to 160 acres—and no individual in a Carey Act scheme can hold a greater area than 160 acres. The condition of desert-land entry that one-eighth of the area must be cultivated before title is given also holds. Previous to construction one year is allowed for working up the details of the scheme, and during this period the Federal Government grants a temporary withdrawal from ordinary entry, which is made final if the scheme is approved.

State Control.

It will be seen from the above that the Federal Government only lays down the broad lines of development and hands over the lands and the supervision of works to the States, with whom the responsibility for the proper carrying out of the works and settlement rests. A Carey Act scheme is therefore controlled chiefly by the legislature of the State in which it lies, and each State has framed its own laws to govern such schemes.

Carey Act schemes are not initiated or constructed by the State Government or with State funds, but by private companies as a commercial venture. These companies, seeing an opportunity to develop desert lands in any State by means of an irrigation scheme, apply to the State for the right to construct the scheme. In their application they have to state for what area they propose to sell water-rights and at what price. The State makes an investigation to see that the water supply and proposed works are sufficient for the area declared, and that the price of sale proposed does not represent an unreasonable profit to the constructing company. If satisfied on these points the State in turn applies to the Federal Government to have the lands embraced in the proposed scheme reserved for this purpose. If approved the lands are handed over to the State, who sell them at a nominal price (usually 50 cents per acre) on condition that the settler undertakes to pay to the constructing company the fixed charges for water-rights. The constructing company does not get possession of the land. All they can sell is the water-right, and that at a price fixed by the State beforehand, so that their maximum profit is the difference between the return from the immediate sale of water-rights at a fixed price over a limited area and the cost of construction. As a matter of fact the profits are usually considerably reduced by the slowness with which the lands are taken up and the payments are made. When the works are nearing completion a date is fixed for throwing open the lands at a fixed price per acre for water-rights. Applications are received before this date, often in excess of the area available, and ownership is usually settled by drawing lots. The State laws, which provide methods for limiting the total area over which water-rights are sold by the constructing company, and the price per acre, are designed to protect the interests of the settler against a company who may wish to make too great a profit or unscrupulously sell rights for a larger area than the available water supply or works are capable of irrigating. These provisions were found to be very necessary as the result of past experience of development by private companies for profit.

The settler obtains title to his land from the State after fulfilling the conditions of residence and cultivation required, and he obtains his water-right from the constructing company when he has fully paid for it, usually in instalments over ten years with 6 per cent. interest, the constructing company holding a first bond on the land till full payment is made.

The Idaho State law requires that the management of the scheme be handed over to the settlers when 35 per cent. of the sums due has been paid by the settlers. The Federal and State Governments take no financial responsibility whatever in these schemes, and the whole risk falls on the constructing company. Several of these have learnt to their cost the same lessons as pointed out in the Reclamation schemes—chiefly, that settlement does not proceed as rapidly as anticipated, that the settler finds difficulty in making the first few payments, and also that actual cost has usually exceeded estimates.

The great feature of the Carey Act is that both the settler and the constructing company enjoy State supervision. For the former, the State sees that the water supply and works are adequate, that the charges are not unreasonable, and that the works be eventually handed over to them; and for the latter it obliges the settler to make an undertaking to pay the water-right charges secured by a first bond on his farm.

Results.

Under the Carey Act over six million acres have been withdrawn from entry for proposed works, and over one million acres have been actually sold to settlers. By far the greatest development under this Act is in the State of Idaho, and the Twin Falls South, Twin Falls

North, Oakley, and Salmon River schemes, previously described in detail, are good examples. At least one of these has not yet been a complete success, the constructing company having failed chiefly on account of an insufficient water supply; but, generally speaking, Carey Act schemes have proved very successful and, on account of the easier conditions of residence and cultivation, have attracted settlers more rapidly than Reclamation schemes.

The two Acts—the Reclamation and the Carey Act—are the two ways in which the Federal Government assists settlement by irrigation, in both cases making practically a gift of the land—in the former carrying out works itself, and in the latter encouraging private capital to carry out the works under the supervision of State authorities.

Private Schemes

Though many settlement schemes have developed quite independently of State assistance, there is a tendency now for the State to exercise some sort of control in all cases.

Large irrigation schemes for settlement have been carried out by private capital and without any assistance from Government in the way of land, except such as is given in the ordinary homestead or desert entry laws.

Thus, in States where the Carey Act has not been applied, as in California, we find a scheme, such as the Imperial Valley scheme, constructed by a private company to irrigate land open to desert entry and therefore not owned by the company. Neither the settler nor the company enjoys State protection. In this case the company takes the risk not only that the settlers will not come, but also that those who do come will not buy water-rights, as there is no law to force them to buy. On the other hand, there was no State authority to protect the settlers by investigating the soundness of the scheme at the outset.

In the Fresno scheme private capital has been employed in a similar way, but the lands were occupied long before the works were carried out. It is significant, however, that in both of these schemes, where the settlers have very little say in the construction or management of the works, the recently constituted Railroad or Public Service Commission, which has the right to regulate the charges and methods of working of commercial enterprises, has been called in.

Irrigation districts are also formed under State laws, and very great development has taken place in this way in California, Idaho, and Colorado States. These districts naturally occur in areas already occupied and not open to entry, and means are usually provided to enable the majority who are in favour of a scheme to force into the scheme an obstructing minority whose lands are included. A description of the details of organization of these districts would require too much space, but in the Modesto-Turlock scheme the general methods have been indicated.

APPENDIX A

First Reclamation Act of 1902

AN ACT appropriating the receipts from the sale and disposal of public lands in certain States and Territories to the construction of irrigation works for the reclamation of arid lands.

Funds provided for Reclamation Work by sale of Public Lands.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That all moneys received from the sale and disposal of public lands in Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming,* beginning with the fiscal year ending June thirtieth, nineteen hundred and one, including the surplus of fees and commissions in excess of allowances to registers and receivers, and excepting the five per centum of the proceeds of the sales of public lands in the above States set aside by law for educational and other purposes, shall be, and the same are hereby, reserved, set aside, and appropriated as a special fund in the Treasury to be known as the "reclamation fund," to be used in the examination and survey for and the construction and maintenance of irrigation works for the storage, diversion, and development of waters for the reclamation of arid and semiarid lands in the said States and Territories, and for the payment of all other expenditures provided for in this Act.

Schemes to be examined and reported to Congress.

SEC. 2. That the Secretary of the Interior is hereby authorized and directed to make examinations and surveys for, and to locate and construct, as herein provided, irrigation works for the storage, diversion, and development of waters, including artesian wells, and to report to Congress at the beginning of each regular session as to the results of such examinations and surveys, giving estimates of cost of all contemplated works, the quantity and location of the lands which can be irrigated therefrom, and all facts relative to the practicability of each irrigation project; also the cost of works in process of construction as well as of those which have been completed.

Lands under proposed Scheme to be withdrawn from entry except under homestead laws, and entry in this case, subject to all payments required by proposed works, and limits of area 40-160 acres.

SEC. 3. That the Secretary of the Interior shall, before giving the public notice provided for in section four of this Act, withdraw from public entry the lands required for any irrigation works contemplated under the provisions of this Act, and shall restore to public entry any of the lands so withdrawn when, in his judgment, such lands are not required for the purposes of this Act; and the Secretary of the Interior is hereby authorized, at or immediately prior to the time of beginning the surveys for any contemplated irrigation works, to withdraw from entry, except under the homestead laws, any public lands believed to be susceptible of irrigation from said works: Provided, that all lands entered and entries made under the homestead laws within areas so withdrawn during such withdrawal shall be subject to all the provisions, limitations, charges, terms, and conditions of this Act; that said surveys shall be prosecuted diligently to completion, and upon the completion thereof, and of the necessary maps, plans, and estimates of cost, the Secretary of the Interior shall determine whether or not said project is practicable and advisable, and if determined to be impracticable or unadvisable he shall thereupon restore said land to entry; that public lands which it is proposed to irrigate by means of any contemplated works shall be subject to entry only under the provisions of the homestead laws in tracts of not less than forty nor more than one hundred and sixty acres, and shall be subject to the limitations, charges, terms, and conditions herein provided: Provided that the commutation provisions of the homestead laws shall not apply to entries made under this Act.

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* Texas included 1906.

Public notice of charges to be made in ten annual instalments on private land and land entered. Charges estimated to repay cost of work.

SEC. 4. That upon the determination by the Secretary of the Interior that any irrigation project is practicable, he may cause to be let contracts for the construction of the same in such portions or sections as it may be practicable to construct and complete as parts of the whole project, providing the necessary funds for such portions or sections are available in the reclamation fund, and thereupon he shall give public notice of the lands irrigible under such project, and limit of area per entry, which limit shall represent the acreage which, in the opinion of the Secretary, may be reasonably required for the support of a family upon the lands in question; also of the charges which shall be made per acre upon the said entries and upon lands in private ownership which may be irrigated by the waters of the said irrigation project, and the number of annual instalments, not exceeding ten, in which such charges shall be paid and the time when such payments shall commence. The said charges shall be determined with a view of returning to the reclamation fund the estimated cost of construction of the project, and shall be apportioned equitably: Provided that in all construction work eight hours shall constitute a day's work, and no Mongolian labour shall be employed thereon.

Entryman must comply with homestead laws and cultivate half area, and make all payments before he gets title. Private owners cannot get water for more than 160 acres. Cancellation on failure to make two annual payments.

SEC. 5. That the entryman upon lands to be irrigated by such works shall, in addition to compliance with the homestead laws, reclaim at least one-half of the total irrigable area of his entry for agricultural purposes, and before receiving patent for the lands covered by his entry shall pay to the Government the charges apportioned against such tract, as provided in section 4. No right to the use of water for land in private ownership shall be sold for a tract exceeding one hundred and sixty acres to any one landowner, and no such sale shall be made to any landowner unless he be an actual bona fide resident on such land, or occupant thereof residing in the neighbourhood of said land, and no such right shall permanently attach until all payments therefor are made. The annual instalments shall be paid to the receiver of the local land office of the district in which the land is situated, and a failure to make any two payments when due shall render the entry subject to cancellation, with the forfeiture of all rights under this Act, as well as of any moneys already paid thereon. All moneys received from the above sources shall be paid into the reclamation fund. Registers and receivers shall be allowed the usual commissions on all moneys paid for lands entered under this Act.

Settlers take over management when major portion of funds paid.

SEC. 6. That the Secretary of the Interior is hereby authorized and directed to use the reclamation fund for the operation and maintenance of all reservoirs and irrigation works constructed under the provisions of this Act: Provided that when the payments required by this Act are made for the major portion of the lands irrigated from the waters of any of the works herein provided for, then the management and operation of such irrigation works shall pass to the owners of the lands irrigated thereby, to be maintained at their expense under such form of organization and under such rules and regulations as may be acceptable to the

Secretary of the Interior: Provided that the title to and the management and operation of the reservoirs and the works necessary for their protection and operation shall remain in the Government until otherwise provided by Congress.

Power to purchase right and land.

SEC. 7. That where in carrying out the provisions of this Act it becomes necessary to acquire any rights or property, the Secretary of the Interior is hereby authorized to acquire the same for the United States by purchase or by condemnation under judicial process, and to pay from the reclamation fund the sums which may be needed for that purpose, and it shall be the duty of the Attorney-General of the United States upon every application of the Secretary of the Interior under this Act to cause proceedings to be commenced for condemnation within thirty days from the receipt of the application at the Department of Justice.

Subject to ordinary State and Federal Law of water.

SEC. 8. That nothing in this Act shall be construed as affecting or intended to affect or to in any way interfere with the laws of any State or Territory relating to the control, appropriation, use, or distribution of water used in irrigation, or any vested right acquired thereunder, and the Secretary of the Interior, in carrying out the provisions of this Act, shall proceed in conformity with such laws, and nothing therein shall in any way affect any right of any State or of the Federal Government or of any landowner, appropriator, or user of water in, to, or from any interstate stream or the waters thereof: Provided that the right to the use of water acquired under the provisions of this Act shall be appurtenant to the land irrigated, and beneficial use shall be the basis, the measure, and the limit of the right.

Later repealed.

SEC. 9.* That it is hereby declared to be the duty of the Secretary of the Interior in carrying out the provisions of this Act, so far as the same may be practicable, and subject to the existence of feasible irrigation projects, to expend the major portion of the funds arising from the sale of public lands within each State and Territory herein before named for the benefit of arid and semiarid lands within the limits of such State or Territory: Provided that the Secretary may temporarily use such portion of said funds for the benefit of arid or semiarid lands in any particular State or Territory herein before named as he may deem advisable, but when so used the excess shall be restored to the fund as soon as practicable, to the end that ultimately, and in any event, within each ten-year period after the passage of this Act, the expenditures for the benefit of the said States and Territories shall be equalized according to the proportions and subject to the conditions as to practicability and feasibility aforesaid.

SEC. 10. That the Secretary of the Interior is hereby authorized to perform any and all acts and to make such rules and regulations as may be necessary and proper for the purpose of carrying the provisions of this Act into full force and effect.

Approved June 17, 1902. (32 Stat., 388.)

ADDITION IN 1906.

TOWN SITES AND LEASING POWER.

AN ACT providing for the withdrawal from public entry of lands needed for town-site purposes in connection with irrigation projects under the Reclamation Act of June seventeenth, nineteen hundred and two, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of the Interior may withdraw from public entry any lands needed for town-site purposes in connection with irrigation projects under the Reclamation Act of June seventeenth, nineteen hundred and two, not exceeding one hundred and sixty acres in each case, and survey and subdivide the same into town lots, with appropriate reservations for public purposes.

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* Sec. 9 of the Reclamation Act is repealed by sec. 6 of the Act of Congress approved June 25, 1910 (36 Stat. L., 835).

SEC. 2. That the lots so surveyed shall be appraised under the direction of the Secretary of the Interior and sold under his direction at not less than their appraised value at public auction to the highest bidders, from time to time, for cash, and the lots offered for sale and not disposed of may afterwards be sold at not less than the appraised value under such regulations as the Secretary of the Interior may prescribe. Reclamation funds may be used to defray the necessary expenses of appraisement and sale, and the proceeds of such sales shall be covered into the reclamation fund.

SEC. 3. That the public reservations in such town sites shall be improved and maintained by the town authorities at the expense of the town; and upon the organization thereof as municipal corporations the said reservations shall be conveyed to such corporations by the Secretary of the Interior, subject to the condition that they will be used forever for public purposes.

SEC. 4. That the Secretary of the Interior shall, in accordance with the provisions of the Reclamation Act, provide for water rights in amount he may deem necessary for the towns established as herein provided, and may enter into contract with the proper authorities of such towns, and other towns or cities on or in the immediate vicinity of irrigation projects, which shall have a water right from the same source as that of said project for the delivery of such water supply to some convenient point, and for the payment into the reclamation fund of charges for the same to be paid by such towns or cities, which charges shall not be less nor upon terms more favourable than those fixed by the Secretary of the Interior for the irrigation project from which the water is taken.

SEC. 5.* That whenever a development of power is necessary for the irrigation of lands under any project undertaken under the said Reclamation Act, or an opportunity is afforded for the development of power under any such project, the Secretary of the Interior is authorized to lease for a period not exceeding ten years, giving preference to municipal purposes, any surplus power or power privilege, and the moneys derived from such leases shall be covered into the reclamation fund and be placed to the credit of the project from which such power is derived: Provided that no lease shall be made of such surplus power or power privilege as will impair the efficiency of the irrigation project.

Approved April 16, 1906. (34 Stat., 116.)

AMENDMENT 1906.

MINIMUM AREA REDUCED TO 10 ACRES AND DESERT LAND ENTRYMEN.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That whenever in the opinion of the Secretary of the Interior, by reason of market conditions and the special fitness of the soil and climate for the growth of fruit and garden produce, a lesser area than forty acres may be sufficient for the support of a family on lands to be irrigated under the provisions of the Act of June seventeenth, nineteen hundred and two, known as the Reclamation Act, he may fix a lesser area than forty acres as the minimum entry and may establish farm units of not less than ten nor more than one hundred and sixty acres.

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*Section 5 amended by Act of February 24, 1911.

PART SEC. 3. If the reclamation project is carried to completion so as to make available a water supply for the land embraced in any such desert-land entry, the entryman shall thereupon comply with all the provisions of the aforesaid Act of June seventeenth, nineteen hundred and two, and shall relinquish all land embraced within his desert land entry in excess of one hundred and sixty acres, and as to such one hundred and sixty acres retained, he shall be entitled to make final proof and obtain patent upon compliance with the terms of payment prescribed in said Act of June seventeenth, nineteen hundred and two, and not otherwise. But nothing herein contained shall be held to require a desert-land entryman who owns a water-right and reclaims the land embraced in his entry to accept the conditions of said Reclamation Act.

Approved June 27, 1906. (34 Stat., 519.)

ASSIGNMENT OF RECLAMATION HOMESTEAD ENTRIES.

AN ACT providing that entrymen for homesteads within reclamation projects may assign their entries upon satisfactory proof of residence, improvement, and cultivation for five years the same as though said entry had been made under the original Homestead Act.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That from and after the filing with the Commissioner of the General Land Office of satisfactory proof of residence, improvement, and cultivation for the five years required by law, persons who have or shall make homestead entries within reclamation projects under the provisions of the Act of June seventeenth, nineteen hundred and two, may assign such entries, or any part thereof, to other persons, and such assignees, upon submitting proof of the reclamation of the lands and upon payment of the charges apportioned against the same as provided in the said Act of June seventeenth, nineteen hundred and two, may receive from the United States a patent for the lands: Provided that all assignments made under the provisions of this Act shall be subject to the limitations, charges, terms, and conditions of the Reclamation Act.

Approved June 23, 1910. (36 Stat. L., 592.)

ADVANCES TO THE RECLAMATION FUND.

AN ACT to authorize advances to the "reclamation fund," and for the issue and disposal of certificates of indebtedness in reimbursement therefor, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That to enable the Secretary of the Interior to complete Government reclamation projects heretofore begun, the Secretary of the Treasury is authorized, upon request of the Secretary of the Interior, to transfer from time to time to the credit of the reclamation fund created by the Act entitled "An Act appropriating the receipts from the sale and disposal of public lands in certain States and Territories to the construction of irrigation works for the reclamation of arid lands," approved June seventeenth, nineteen hundred and two, such sum or sums, not exceeding in the aggregate twenty million dollars, as the Secretary of the Interior may deem necessary to complete the said reclamation projects, and such extensions thereof as he may deem proper and necessary to the successful and profitable operation and maintenance thereof or to protect water rights pertaining thereto claimed by the United States, provided the same shall be approved by the President of the United States; and such sum or sums as may be required to comply with the foregoing authority are hereby appropriated out of any money in the Treasury not otherwise appropriated: Provided that the sums hereby authorized to be transferred to the reclamation fund shall be so transferred only as such sums shall be actually needed to meet payments for work performed under existing law: And provided further, that all sums so transferred shall be reimbursed to the Treasury from the reclamation fund, as herein after provided: And provided further, that no part of this appropriation shall be expended upon any existing project until it shall have been examined and reported upon by a board of engineer officers of the Army designated by the President of the United States, and until it shall be approved by the President as feasible and practicable and worthy of such expenditure; nor shall any portion of this appropriation be expended upon any new project.

SEC. 2. That for the purpose of providing the Treasury with funds for such advances to the reclamation fund, the Secretary of the Treasury is authorized to issue certificates of indebtedness of the United States in such form as he may prescribe and in denominations of fifty dollars, or multiples of that sum; said certificates to be redeemable at the option of the United States at any time after three years from the date of their issue and to be payable five years after such date, and to bear interest, payable semiannually, and not exceeding three per centum per annum; the principal and interest to be payable in gold coin of the United States. The certificates of indebtedness herein authorized may be disposed of by the Secretary of the Treasury at not less than par, under such rules and regulations as he may prescribe, giving all citizens of the United States an equal opportunity to subscribe therefor, but no commission shall be allowed and the aggregate issue of such certificates shall not exceed the amount of all advances made to said reclamation fund, and in no event shall the same exceed the sum of twenty million dollars. The certificates of indetedness herein authorized shall be exempt from taxes or duties of the United States as well as from taxation in any form by or under state, municipal, or local authority; and a sum not exceeding one-tenth of one per centum of the amount of the certificates of indebtedness issued under this Act is hereby appropriated, out of any money in the Treasury not otherwise appropriated, to pay the expense of preparing, advertising, and issuing the same.

SEC. 3. That beginning five years after the date of the first advance to the reclamation fund under this Act, fifty per centum of the annual receipts of the reclamation fund shall be paid into the general fund of the Treasury of the United States until payment so made shall equal the aggregate amount of advances made by the Treasury to the said reclamation fund, together with interest paid on the certificates of indebtedness issued under this Act and any expense incident to preparing, advertising, and issuing the same.

SEC. 4. That all money placed to the credit of the reclamation fund in pursuance of this Act shall be devoted exclusively to the completion of work on reclamation projects heretofore begun as herein before provided, and the same shall be included with all other expenses in future estimates of construction, operation, or maintenance, and hereafter no irrigation project contemplated by said Act of June seventeenth, nineteen hundred and two, shall be begun unless and until the same shall have been recommended by the Secretary of the Interior and approved by the direct order of the President of the United States.

SEC 5.* That no entry shall be hereafter made and no entryman shall be permitted to go upon lands reserved for irrigation purposes until the Secretary of the Interior shall have established the unit of acreage and fixed the water charges and the date when the water can be applied and made public announcement of the same.

SEC. 6. That section nine of said Act of Congress, approved June seventeenth, nineteen hundred and two, entitled "An Act appropriating the receipts from the sale and disposal of public lands in certain States and Territories to the construction of irrigation works for the reclamation of arid lands," is hereby repealed.

Approved June 25, 1910. (36 Stat. L., 835.)

AN ACT to authorize the Secretary of the Interior to withdraw public notices issued under section four of the Reclamation Act, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of the Interior may, in his discretion, withdraw any public notice heretofore issued under section four of the Reclamation Act of June seventeenth, nineteen hundred and two, and he may agree to such modification of water-right applications heretofore duly filed or contracts with water users' associations and others, entered into prior to the passage of this Act, as he may deem advisable, or he may consent to the abrogation of such water-right applications and contracts, and proceed in all respects as if no such notice had been given.

Approved February 13, 1911. (36 Stat. L., 902.)

AN ACT to amend section five of the Act of Congress of June twenty-fifth, nineteen hundred and ten, entitled "An Act to authorize advances to the 'reclamation fund,' and for the issue and disposal of certificates of indebtedness in reimbursement therefor, and for other purposes."

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That section five of an Act entitled "An Act to authorize advances to the 'reclamation fund,' and for the issue and disposal of certificates of indebtedness in reimbursement therefor, and for other purposes," approved June twenty-fifth, nineteen hundred and ten (Thirty-sixth Statutes at Large, page eight hundred and thirty-five), be, and the same hereby is, amended as follows:

"SEC. 5. That no entry shall be hereafter made and no entryman shall be permitted to go upon lands reserved for irrigation purposes until the Secretary of the Interior shall have established the unit of acreage and fixed the water charges and the date when the water can be applied and make public announcement of the same: Provided that where entries made prior to June twenty-fifth, nineteen hundred and ten, have been or may be relinquished in whole or in part, the lands so relinquished shall be subject to settlement and entry under the homestead law as amended by an Act entitled 'An Act appropriating the receipts from the sale and disposal of the public lands in certain States and Territories to the construction of irrigation works for the reclamation of arid lands,' approved June seventeenth, nineteen hundred and two (Thirty-second Statutes at Large, page three hundred and eighty-eight)."

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* Amended by Act of Congress approved February 18, 1911.

Approved February 18, 1911. (36 Stat. L. 917.)

DISPOSITION OF SURPLUS WATERS AND CO-OPERATION IN CONSTRUCTION.

[Warren Act.]

AN ACT to authorize the Government to contract for impounding, storing and carriage of water, and to co-operate in the construction and use of reservoirs and canals under reclamation projects, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That whenever in carrying out the provisions of the reclamation law, storage or carrying capacity has been or may be provided in excess of the requirements of the lands to be irrigated under any project, the Secretary of the Interior, preserving a first right to lands and entrymen under the project, is hereby authorized, upon such terms as he may determine to be just and equitable, to contract for the impounding, storage, and carriage of water to an extent not exceeding such excess capacity with irrigation systems operating under the Act of August eighteenth, eighteen hundred and ninety-four, known as the Carey Act, and individuals, corporations, associations, and irrigation districts organized for or engaged in furnishing or in distributing water for irrigation. Water so impounded, stored, or carried under any such contract shall be for the purpose of distribution to individual water users by the party with whom the contract is made: Provided, however, that water so impounded, stored, or carried shall not be used otherwise than as prescribed by law as to lands held in private ownership within Government reclamation projects. In fixing the charges under any such contract for impounding, storing, or carrying water for any irrigation system, corporation, association, district, or individual, as herein provided, the Secretary shall take into consideration the cost of construction and maintenance of the reservoir by which such water is to be impounded or stored and the canal by which it is to be carried, and such charges shall be just and equitable as to water users under the Government project. No irrigation system, district, association, corporation, or individual so contracting shall make any charge for the storage, carriage, or delivery of such water in excess of the charge paid to the United States except to such extent as may be reasonably necessary to cover cost of carriage and delivery of such water through their works.

SEC. 2. That in carrying out the provisions of said Reclamation Act and Acts amendatory thereof or supplementary thereto, the Secretary of the Interior is authorized, upon such terms as may be agreed upon, to co-operate with irrigation districts, water users' associations, corporations, entrymen, or water users for the construction or use of such reservoirs, canals, or ditches as may be advantageously used by the Government and irrigation districts, water users' associations, corporations, entrymen, or water users for impounding, delivering, and carrying water for irrigation purposes: Provided that the title to and management of the works so constructed shall be subject to the provisions of section six of said Act: Provided further that water shall not be furnished from any such reservoir or delivered through any such canal or ditch to any one landowner in excess of an amount sufficient to irrigate one hundred and sixty acres: Provided that nothing contained in this Act shall be held or construed as enlarging or attempting to enlarge the right of the United States, under existing law, to control the waters of any stream in any State.

SEC. 3. That the moneys received in pursuance of such contracts shall be covered into the reclamation fund and be available for use under the terms of the Reclamation Act and the Acts amendatory thereof or suplementary thereto.

Approved February 21, 1911. (36 Stat. L., 925.)

AN ACT FOR THE RELIEF OF HOMESTEAD ENTRYMEN UNDER THE RECLAMATION PROJECTS IN THE UNITED STATES.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That no qualified entryman who prior to June twenty-fifth, nineteen hundred and ten, made bona fide entry upon lands proposed to be irrigated under the provisions of the Act of June seventeenth, nineteen hundred and two, the national reclamation law, and who established residence in good faith upon the lands entered by him, shall be subject to contest for failure to maintain residence or make improvements upon his land prior to the time when water is available for the irrigation of the lands embraced in his entry, but all such entrymen shall, within ninety days after the issuance of the public notice required by section four of the Reclamation Act, fixing the date when water will be available for irrigation, file in the local land office a water-right application for the irrigable lands embraced in his entry, in conformity with the public notice and approved farm-unit plat for the township in which his entry lies, and shall also file an affidavit that he has re-established his residence on the land with the intention of maintaining the same for a period sufficient to enable him to make final proof: Provided that no such entryman shall be entitled to have counted as part of the required period of residence any period of time during which he was not actually upon the said land prior to the date of the notice aforesaid, and no application for the entry of said lands shall be received until after the expiration of the ninety days after the issuance of notice within which the entryman is hereby required to re-establish his residence and apply for water-right.

Approved April 30, 1912. (37 Stat., 105.)

AN ACT PROVIDING FOR PATENTS ON RECLAMATION ENTRIES, AND FOR OTHER PURPOSES.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That any homestead entryman under the Act of June seventeenth, nineteen hundred and two, known as the Reclamation Act, including entrymen on ceded Indian lands, may, at any time after having complied with the provisions of law applicable to such lands as to residence, reclamation, and cultivation, submit proof of such residence, reclamation, and cultivation, which proof, if found regular and satisfactory, shall entitle the entryman to a patent, and all purchasers of water-right certificates on reclamation projects shall be entitled to a final water-right certificate upon proof of the cultivation and reclamation of the land to which the certificate applies, to the extent required by the Reclamation Act for homestead entrymen: Provided that no such patent or certificate shall issue until all sums due the United States on account of such land or water-right at the time of issuance of patent or certificate have been paid.

SEC 2. That every patent and water-right certificate issued under this Act shall expressly reserve to the United States a prior lien on the lands patented or for which water-right is certified, together with all water-rights appurtenant or belonging thereto, superior to all other liens, claims, or demands whatsoever for the payment of all sums due or to become due to the United States or its successors in control of the irrigation project in connection with such lands and water-rights.

Upon default of payment of any amount so due title to the land shall pass to the United States free of all encumbrance, subject to the right of the defaulting debtor or any mortgagee, lien holder, judgment debtor, or subsequent purchaser to redeem the land within one year after the notice of such default shall have been given by payment of all moneys due, with eight per centum interest and cost. And the United States, at its option, acting through the Secretary of the Interior, may cause land to be sold at any time after such failure to redeem, and from the proceeds of the sale there shall be paid into the reclamation fund all moneys due, with interest as herein provided, and costs. The balance of the proceeds, if any, shall be the property of the defaulting debtor or his assignee: Provided that in case of sale after failure to redeem under this section the United States shall be authorized to bid in such land at not more than the amount in default, including interest and costs.

SEC. 3. That upon full and final payment being made of all amounts due on account of the building and betterment charges to the United States or its successors in control of the project, the United States or its successors, as the case may be, shall issue upon request a certificate certifying that payment of the building and betterment charges in full has been made, and that the lien upon the land has been so far satisfied and is no longer of any force or effect except the lien for annual charges for operation and maintenance: Provided that no person shall at any one time or in any manner, except as herein after otherwise provided, acquire, own, or hold irrigable land for which entry or water-right application shall have been made under the said Reclamation Act of June seventeenth, nineteen hundred and two, and Acts supplementary thereto and amendatory thereof, before final payment in full of all instalments of building and betterment charges shall have been made on account of such land in excess of one farm unit as fixed by the Secretary of the Interior as the limit of area per entry of public land or per single ownership of private land for which a water-right may be purchased respectively, nor in any case in excess of one hundred and sixty acres, nor shall water be furnished under said Acts nor a water-right sold or recognized for such excess; but any such excess land acquired at any time in good faith by descent, by will, or by foreclosure of any lien may be held for two years and no longer after its acquisition; and every excess holding prohibited as aforesaid shall be forfeited to the United States by proceedings instituted by the Attorney-General for that purpose in any court of competent jurisdiction; and this proviso shall be recited in every patent and water-right certificate issued by the United States under the provisions of this Act.

SEC. 4. That the Secretary of the Interior is hereby authorized to designate such bonded fiscal agents or officers of the Reclamation Service as he may deem advisable on each reclamation project, to whom shall be paid all sums due on reclamation entries or water-rights, and the officials so designated shall keep a record for the information of the public of the sums paid and the amount due at any time on account of any entry made or water-right purchased under the Reclamation Act; and the Secretary of the Interior shall make provision for furnishing copies of duly authenticated records of entries upon payment of reasonable fees, which copies shall be admissible in evidence, as are copies authenticated under section eight hundred and eighty-eight of the Revised Statutes.

SEC. 5. That jurisdiction of suits by the United States for the enforcement of the provisions of this Act is hereby conferred on the United States district courts of the districts in which the lands are situated.

Approved August 9, 1912. (37 Stat., 265.)

AN ACT making appropriations to supply deficiencies in appropriations for the fiscal year nineteen hundred and twelve and for prior years, and for other purposes.

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That any desert-land entryman whose desert-land entry has been embraced within the exterior limits of any land withdrawal or irrigation project under the Act of June seventeenth, nineteen hundred and two, known as the Reclamation Act, and who may have obtained a water supply for the land embraced in any such desert-land entry from the reclamation project by the purchase of a water-right certificate, may at any time after having complied with the provisions of the law applicable to such lands and upon proof of the cultivation and reclamation of the land to the extent required by the Reclamation Act for homestead entrymen, submit proof of such compliance, which proof, if found regular and satisfactory, shall entitle the entryman to a patent and a final water-right certificate under the same terms and conditions as required of homestead entrymen under the Act entitled "An Act providing for Patents on Reclamation Entries and for other purposes, approved August ninth, nineteen hundred and twelve."

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Approved August 26, 1912. (37 Stat., 610.)

APPENDIX B

The Carey Act.

THE original Carey Act of 1894 is as follows:—

"That to aid the public-land States in the reclamation of the desert lands therein, and the settlement, cultivation, and sale thereof in small tracts to actual settlers, the Secretary of the Interior, with the approval of the President, be, and hereby is, authorized and empowered, upon proper application of the State, to contract and agree from time to time with each of the States in which there may be situated desert lands as defined by the Act entitled 'An Act to provide for the Sale of Desert Land in certain States and Territories,' approved March third, eighteen hundred and seventy-seven, and the Act amendatory thereof, approved March third, eighteen hundred and ninety-one, binding the United States to donate, grant, and patent to the State, free of cost for survey or price, such desert lands, not exceeding one million acres in each State, as the State may cause to be irrigated, reclaimed, occupied, and not less than twenty acres of each one hundred and sixty acre tract cultivated by actual settlers, within ten years next after the passage of this Act, as thoroughly as is required of citizens who may enter under the said desert-land law. Before the application of any State is allowed or any contract or agreement is executed or any segregation of any of the land from the public domain is ordered by the Secretary of the Interior, the State shall file a map of the said land proposed to be irrigated, which shall exhibit a plan showing the mode of the contemplated irrigation, and which plan shall be sufficient to thoroughly irrigate and reclaim said land and prepare it to raise ordinary agricultural crops, and shall also show the source of the water to be used for irrigation and reclamation, and the Secretary of the Interior may make necessary regulations for the reservation of the lands applied for by the States to date from the date of the filing of the map and plan of irrigation; but such reservation shall be of no force whatever if such map and plan of irrigation shall not be approved. That any State contracting under this section is hereby authorized to make all necessary contracts to cause the said lands to be reclaimed and to induce their settlement and cultivation in accordance with and subject to the provisions of this section; but the State shall not be authorized to lease any of said lands or to use or dispose of the same in any way whatever, except to secure their reclamation, cultivation, and settlement. As fast as any State may furnish satisfactory proof, according to such rules and regulations as may be prescribed by the Secretary of the Interior, that any of said lands are irrigated, reclaimed, and occupied by actual settlers, patents shall be issued to the State or its assigns for said lands so reclaimed and settled: Provided that said States shall not sell or dispose of more than one hundred and sixty acres of said lands to any one person, and any surplus of money derived by any State from the sale of said lands in excess of the cost of their reclamation shall be held as a trust fund for and be applied to the reclamation of other desert lands in such State. That to enable the Secretary of the Interior to examine any of the lands that may be selected under the provisions of this section there is hereby appropriated out of any money in the Treasury not otherwise appropriated, one thousand dollars."

Little development took place under this Act as it stood, because the lands were not handed over to the State until partially cultivated. This was remedied in 1896 by the following Act:—

"A lien or liens is hereby authorized to be created by the State to which such lands are granted and by no other authority whatever, and when created shall be valid on and against the separate legal sub-divisions of land reclaimed, for the actual cost and necessary expenses of reclamation and reasonable interest thereon from the date of reclamation until disposed of to actual settlers; and when an ample supply of water is actually furnished in a substantial ditch or canal, or by artesian wells or reservoirs, to reclaim a particular tract or tracts of such lands, then patents shall issue for the same to such State without regard to settlement or cultivation: Provided that in no event, in no contingency, and under no circumstances shall the United States be in any manner directly or indirectly liable for any amount of any such lien or liability in whole or in part."

A further defect of the original Act kept back development, and this was the limitation of ten years from the date of passage, i.e., from 1894-1904. This was remedied in 1902 as follows:—

"That section four of the Act, eighteen hundred and ninety-four, is hereby amended so that the ten years' period within which any State shall cause the lands applied for under said Act to be irrigated and reclaimed, as provided in said section, as amended by the Act of June 11, 1896, shall begin to run from the date of approval by the Secretary of the Interior of the State's application for the segregation of such lands; and if the State fails within said ten years to cause the whole or any part of the lands so segregated to be so irrigated and reclaimed, the Secretary of the Interior may, in his discretion, continue said segregation for a period of not exceeding five years, or may, in his discretion, restore such lands to the public domain."

After this alteration development was rapid. It was found, however, that big schemes required considerable time to be worked up, and, to prevent other speculators from cutting in during the making of investigations and plans, an amendment was passed in 1910 allowing the withdrawal "temporarily from settlement or entry areas embracing lands for which the State or Territory proposes to make application pending the investigation and survey preliminary to the filing of maps and plats and application for the segregation"; it being provided "that if the State or Territory shall not present its application for segregation and maps and plats within one year after such temporary withdrawal, the lands so withdrawn shall be restored to entry as though such withdrawal had not been made."

The above are the chief Federal Acts dealing with Carey Act Settlement. The details of actual working are left to the various State Legislatures. The following are abstracts from the laws of Idaho State, which illustrate the relation of the State to the constructing company and settler:—

"CONTRACT BETWEEN STATE AND PROPOSED CONTRACTOR.

"SEC. 1621. Upon the withdrawal of the land by the (Federal) Department of the Interior, it shall be the duty of the (State) Board to enter into a contract with the parties submitting the proposal, which contract shall contain complete specifications of the location, dimensions, character, and estimated cost of the proposed ditch, canal, or other irrigation works; the price and terms per acre at which such works and perpetual water-rights shall be sold to settlers; and the price and terms upon which the State is to dispose of the lands to settlers. This contract shall not be entered into on the part of the State until the withdrawal of the lands by the Department of the Interior and the filing of a satisfactory bond on the part of the proposed contractor for irrigation works, which bond shall be in a penal sum equal to five per cent. of the estimated cost of the works, and shall be conditioned for the faithful performance of the provisions of the contract with the State.

"SEC. 1622. No contract shall be made by the Board which requires a greater time than five years for the construction of the works, and all contracts shall state that the work shall begin within six months from date of contract; that at least one-tenth of the construction work shall be completed within two years from the date of said contract; that construction shall be prosecuted diligently and continuously to completion, and that a cessation of work under the contract with the State for a period of six months after the second year, without the sanction of the Board, will forfeit to the State all rights under said contract.

"SEC. 1623. Upon the failure of any parties having contracts with the State for the construction of irrigation works to begin the same within the time specified by the contract, or to complete the same within the time or in accordance with the specifications of the contract with the State, to the satisfaction of the State Engineer, it shall be the duty of the Register to give such parties written notice of such failure; and if, after a period of sixty days from the sending of such notice, they shall have failed to proceed with the work or to conform to the specifications of their contract with the State, the bond and contract of such parties and all works constructed thereunder shall be at once and thereby forfeited to the State; and it shall be the duty of the Board at once to declare and to give notice once each week for a period of four weeks in some newspaper of general circulation in the country in which the work is situated, and in one newspaper at the State capital in like manner and for a like period of the forfeiture of said contract, and that upon a fixed day proposals will be received at the office of the Board in the Capitol at Boise City for the purchase of the incompleted works and for the completion of said contract, the time for receiving said bids to be at least sixty days subsequent to the issuing of the last notice of forfeiture. The money received by the Board from the sale of partially completed works under the provisions of this section shall first be applied to the expenses incurred by the State in their forfeiture and disposal, and to satisfying the bond; and the surplus, if any exists, shall be paid to the original contractors with the State."

STATE NOT TO BE RESPONSIBLE FOR WORK.

"SEC. 1624. Nothing in this chapter shall be construed as authorizing the Board to obligate the State to pay for any work constructed under any contract, or to hold the State in any way responsible to settlers for the failure of contractors to complete the work according to the terms of their contracts with the State."

It is required of the settler in applying to the State for land that "such application must be accompanied by a certified copy of a contract for a perpetual water-right made and entered into by the party making application with the person, company, or association who has been authorized by the Board to furnish water for the reclamation of such lands."

PROOF OF RECLAMATION BY SETTLERS.

"SEC. 1628. Within one year after any person, company of persons, association or incorporated company, authorized to construct irrigation works under the provisions of this chapter shall have notified the settlers under such works that they are prepared to furnish water under the terms of their contract with the State, the said settler shall cultivate and reclaim not less than one-sixteenth part of the land filed upon, and within two years after the said notice the settler shall have actually irrigated and cultivated not less than one-eighth of the land filed upon, and within three years from the date of said notice the settler shall make final proof of reclamation, settlement, and occupation, which proof shall embrace evidence that he is the owner of shares in the works which entitle him to a water-right for his entire tract of land sufficient in volume for the complete irrigation and reclamation thereof; that he has been an actual settler thereon, and has cultivated and irrigated not less than one-eighth part of said tract."

WATER CONTRACTS A LIEN ON LAND: FORECLOSURES.

"SEC. 1629. . . . The water-rights to all lands acquired under the provisions of this chapter shall attach to and become appurtenant to the land as soon as title passes from the United States to the State. Any person, company, or association furnishing water for any tract of land, shall have a first and prior lien on said water-right and land upon which such water is used for all deferred payments for said water-right, said lien to be in all respects prior to any and all other liens created or attempted to be created by the owner and possessor of said land; said lien to remain in full force and effect until the last deferred payment for the water-right is fully paid and satisfied according to the terms of the contract under which said water-right was acquired."

CHAPTER XVIII

IRRIGATION LAW

The Law of Prior Appropriation.

THERE is no general Irrigation Act such as we have in South Africa which would apply throughout the whole of the United States. All State law is subject to the Federal law, but the Federal Government has scarcely touched irrigation law, and the Federal courts consequently only deal with irrigation disputes when the matter concerns more than one State. Apart from inter-State difficulties, therefore, each State frames its own irrigation laws quite independently of any Federal control.

It is natural to suppose that in consequence there would be considerable differences in the irrigation laws of the various States. As a matter of fact, if we exclude California and two or three other States, there is a remarkable resemblance in the general principles of irrigation law in the majority of Western States, especially in the fundamental doctrine of prior appropriation. Idaho and Colorado will be taken as examples in the following description of this doctrine because storage questions are beginning to be of importance in these States, in both of which I visited the State Engineers' offices.

The fundamental principle of the law of prior appropriation may be gathered from the following extract from the Constitutions of these two States. The Colorado Constitution lays it down that "the right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied. Priority of appropriation shall give the better right as between those using the water for the same purposes," and domestic use has preference over agricultural and the latter over manufacturing use.

In the Idaho Constitution we find the same words, with the addition that "priority in time shall give superiority of right in the numerical order of settlement and improvement."

We should first note that use of the water is not restricted to owners of riparian land, i.e. to those whose land is actually bordering on the stream.

The above law makes it clear that the first man, A, to decide to use the waters of a stream for irrigation establishes a right to as much water as he can beneficially use, and any other person, B, deciding to carry out a scheme at a later date, whether higher up or lower down the stream, can in the same way establish a right to as much water as he can beneficially use, but only after A's prior right has been satisfied. Similarly, C, D, etc., can establish rights to what remains after A and B have been satisfied, and if A then decides to enlarge his work, he gets an additional right, but only after B, C, D, etc., who in the meantime obtained rights, have received the flow which they have appropriated.

So long as the conditions fixed by the State for determining beneficial use are fulfilled, there is no limit to the amount of the appropriation. Thus, if the first man, A, decides to carry out a work capable of utilizing the whole flow of the stream and actually carries out such scheme and proves beneficial use, then that is an end to the possible development from that stream. No one, not even a riparian owner, can then disturb A's right to the whole flow.

The great advantages of this principle are that the pioneers in development have their reward in definite water-rights which can not be upset by later developments above them, and that the establishment of rights along a stream becomes almost automatic. As a matter of fact, the State now provides an organization for recording the times of appropriation in order, for seeing that the works are carried out and beneficial use made within specified times, and for supervising the actual distribution of water according to the rights obtained by appropriation. This organization will be dealt with after seeing how the principle works in a few typical cases.

We shall first consider direct irrigation without storage. It is only recently that the need for storage has become apparent. The early laws contemplated only direct leading by furrows. In the early stages of development there was usually enough water for considerable development by direct irrigation, and the need for great economy in use was not pressing. Consequently, in fixing some measure of reasonable use, the only limit set to the amount of water appropriated was a maximum rate of flow proportioned to the area. In Idaho this was

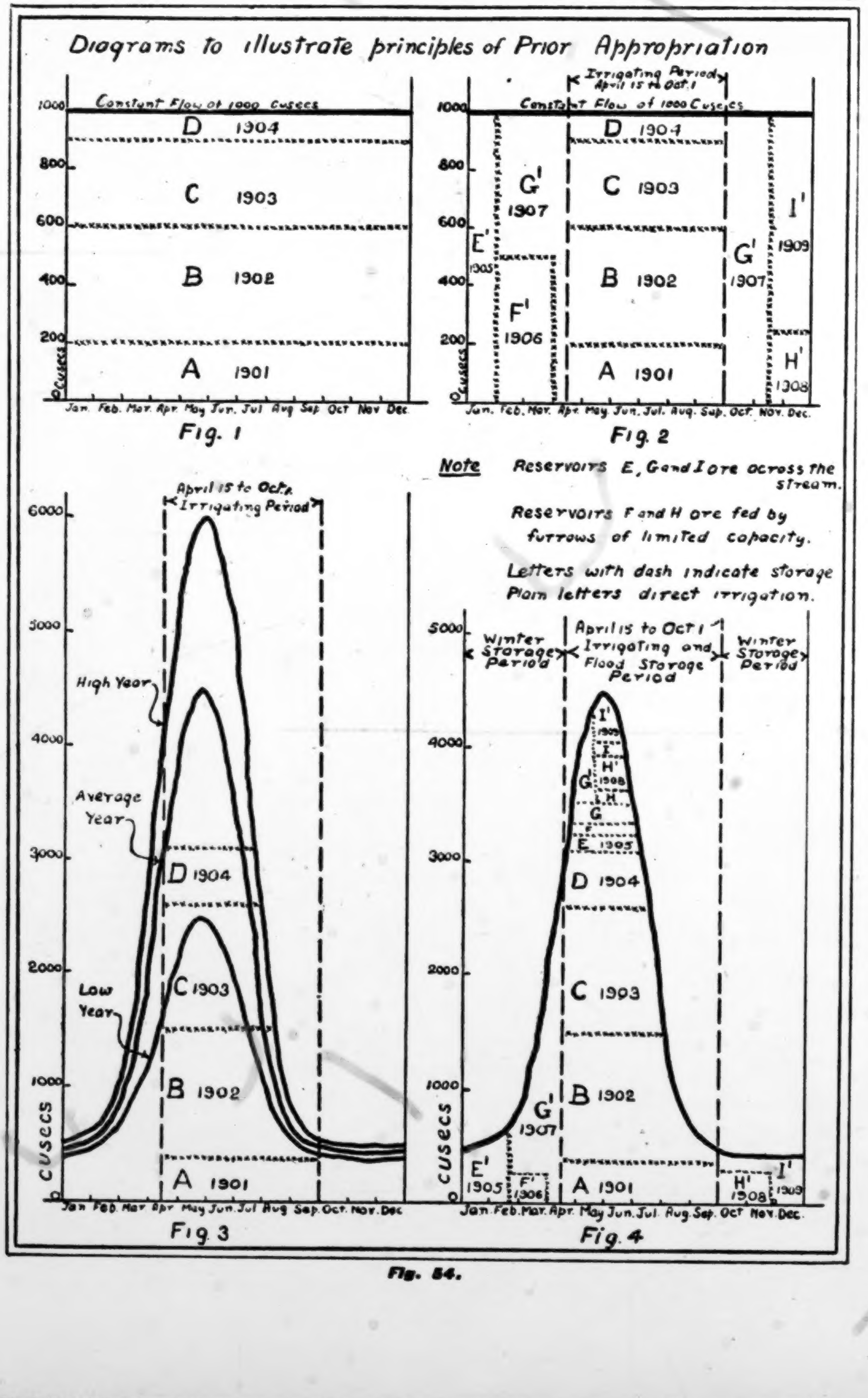
Diagrams to illustrate principles of Prior Appropriation
Constant Flow of 1000 Cusecs
D 1904
C 1903
B 1902
A 1901
1000
800
600
400
200
0
Cusecs
Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.
Fig. 1
Irrigating Period April 15 to Oct. 1
Constant Flow of 1000 Cusecs
D 1904
C 1903
B 1902
A 1901
G' 1907
E' 1905
F' 1906
G' 1907
I' 1909
H' 1908
Fig. 2
Note Reservoirs E, G and I are across the stream.
Reservoirs F and H are fed by furrows of limited capacity.
Letters with dash indicate storage
Plain letters direct irrigation.
April 15 to Oct. 1 Irrigating Period
6000
5000
4000
3000
2000
1000
0
High Year
Average Year
Low Year
D 1904
C 1903
B 1902
A 1901
Cusecs
Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.
Fig 3
Winter Storage Period
April 15 to Oct 1 Irrigating and Flood Storage Period
Winter Storage Period
5000
4000
3000
2000
1000
0
I' 1909
I
H' 1908
H
G
G
E 1905
D 1904
C 1903
B 1902
G' 1907
E' 1905
F' 1906
A 1901
H' 1908
I' 1909
Cusecs
Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sep. Oct. Nov. Dec.
Fig. 4

Fig. 54.

fixed as 1-50th cusec per acre, and practically all rights have been determined in amount on this basis.

Consider first an imaginary stream with a constant flow of 1000 cusecs throughout the year, neglecting losses or gains en route by seepage or tributaries.

The graph of such a river would be represented by the full horizontal line of fig. 1.

The first to appropriate water is A in 1901, and he proves beneficial use for 10,000 acres and establishes a right to 200 cusecs. B then comes along in 1902 with a scheme for 20,000 acres, and by beneficial use establishes a right to 400 cusecs. C comes later, in 1903, with a scheme for 15,000 acres and establishes a right to 300 cusecs. In 1904, D wishes to irrigate as large an area as possible, but, as A, B, and C have established rights to a total of 900, there are only 100 cusecs left, and he can therefore claim this for 5000 acres. The possible development for this stream being now complete, no one else has a right to use the water of the stream for direct irrigation. As this imaginary river has a constant flow, A has no advantage over B or C, all enjoying equal security against others who wish to use the water. But suppose that the constant flow suddenly falls to 800 cusecs, the result will be that D gets no water at all, and C, even if he is situated above B and A, must let 600 cusecs pass down to them and can only use the balance of 200 cusecs.

We have assumed that all the irrigators require the water throughout the year, as they do in the South. In Idaho and Colorado, and generally in the North, irrigation is practised only for a part of the year—in summer—and no water is required for direct irrigation during winter. By limiting the period of the year during which the right to direct flow can be exercised, it is therefore feasible to extend the possibilities of the imaginary stream by storage works which will conserve the winter flow. Suppose we take the storage period (as fixed in Colorado) to be from 1st October to 15th April, the rights of A, B, C, and D will then be restricted by the vertical dotted lines shown in fig. 2, and the areas to right and left will be available for storage.

The principle of priority of appropriation is held to apply to storage as well as to direct irrigation. In the case of storage, instead of the rate of flow, the total volume that can be stored is limited by a maximum proportioned to the area to be irrigated. In Idaho this maximum is fixed at 5 acre-feet per acre, and each reservoir is allowed to take out this maximum once a year during the storage period and in order of priority. It is necessary to distinguish between two types of storage work, one across the stream and the other away from the stream and fed by a furrow of limited capacity.

Suppose, then, in 1905, E is the first to propose a reservoir across the stream to irrigate 12,000 acres. He acquires a right to 60,000 acre-feet by beneficial use and fills his reservoir by taking the whole flow for approximately one month (assuming 1 cusec as equivalent to 60 acre-feet per month). The date at which the first appropriator is to begin storing has to be fixed, but 1st January appears to be the date in Colorado. By the end of January, then, E has stored his limit of 60,000 acre-feet (as represented by area E, fig. 2) and thereafter must allow to flow out of his reservoir as much as comes in.

In 1906, F builds a reservoir away from the stream to irrigate 12,000 acres, and constructs a furrow with a maximum capacity of 500 cusecs to feed it. It will take him roughly two months to fill his reservoir to the maximum capacity allowed, viz. 60,000 acre-feet, and he begins after E has filled his reservoir.

In 1907, G, situated above all the other irrigators, constructs a dam across the stream to store 180,000 acre-feet for 36,000 acres. During January he must pass the whole flow down to E; during February and March he must pass 500 cusecs to F and can store the balance during these two months, and from 1st to 15th April he can take the whole flow. By 15th April he has not yet filled his reservoir, but now the period of direct irrigation begins, and, after 15th April, he cannot store any of the flow. He must pass the whole down for A, B, C, and D, and probably, in addition, passes down most of his stored water for irrigating his own lands. On 1st October he continues storing water, and can take the balance of the 180,000 acre-feet which he could not get before the irrigating season, and he will have exhausted his right by about the middle of November. This water he holds over for next year. In 1908, H appropriates, for about 4600 acres, about 22,500 acre-feet for an outside reservoir to be fed by a furrow of 250 cusecs capacity, and, in 1909, I takes for about 14,000 acres all that is left by means of a reservoir across the stream. Both H and I hold the water for next year. This imaginary stream with a constant flow illustrates the general methods of the law of prior appropriation, though with regard to storage it should be noted that in both States there is still considerable uncertainty as to the law.

From this imaginary river we can pass to the conditions on an actual river. Instead of the straight line of constant flow the graph of flow will be a curve with several peaks, and the curve for each year will be different. The curves giving the average flow for a number of years for snow-fed rivers of the North will have the same general characteristics as given in fig. 14 for the Boise River with a pronounced maximum in early summer when the snows melt rapidly. The curve for each year will, of course, have more peaks than one, but for simplicity we shall keep to a curve with a single peak. Fig. 3 represents the graph of such a river for an average, a high, and a low year. The advantage of priority is now more apparent. A gets his full supply throughout the irrigating period in good and bad years. B and C get their full supplies for shorter periods, and D runs the risk, in a low year, of getting no water at all.

Suppose D is the last who will take the risk of carrying out a work depending only on direct leading. Further development is then by storage, and the principle of priority is again followed. E (fig. 4), who follows, will appropriate a certain volume at the rate of 5 acre-feet per acre, and probably, at the same time, a direct flow at the rate of 1-50th cusec per acre, but his total in both ways must not exceed 5 acre-feet in the year. He will probably not fill his reservoir to full capacity before the irrigating season, but will stop short by as much as he estimates he will take by direct flow at a much slower rate during the irrigating period. Even if those who follow continue to appropriate most of the flow outside the irrigating period, there will still be left a volume—at the peak of the flood—in excess of the direct-flow appropriations, and this would run to waste unless some arrangement were made for appropriating it by storage. This excess appears to have been classed separately as "flood flow," as opposed to "normal flow," in the latest Idaho Regulations (1913) (see Appendix), and is liable to storage in the same way as winter flow, the person or persons whose turn it is to fill up their reservoirs taking their water from this excess instead of waiting till the close of the irrigating period. Fig. 4 illustrates a possible arrangement for complete use of the water in an average year.

If another person, say X, decides to construct a furrow solely for direct irrigation after G's but before H's reservoir appropriation, it is not clear whether he has the right to begin irrigating while G is still filling up, or whether he has to wait till G is filled up.

The horizontal lines separating the users during the irrigating period have been drawn straight, indicating that each irrigator uses the maximum flow he is entitled to throughout the whole period. As a matter of fact, there will be periods when less than the maximum flow will be used. The lines will then be curved downwards to the advantage of later appropriators.

Much of the preceding discussion of storage is based on rules only recently framed. In actual practice there has been considerable lack of method in regulating storage appropriations. In Idaho the first regulations for storage as distinct from direct irrigation were published only in March, 1913, and as yet there is no example of the adjustment of priorities of storage for a number of reservoirs along one stream or of the more complicated problem where appropriations for direct flow only are made after storage appropriations. Where streams such as the Boise, Salmon River, and Cottonwood Creek have been almost fully developed, the problem has been simplified by the construction of a single huge reservoir on each stream, and the question of dividing water for different storage works does not arise.

In Colorado there is an example on the Cache La Poudre River where very high development has been reached by a number of storage reservoirs. But these are mostly situated away from the river and are fed by furrows; the problem is therefore an easier one than where the reservoirs are across the stream with no limit to the capacity of intake. On this river an interesting system of exchange has been developed which will be referred to later.

From the above outline of the principles of the law of prior appropriation, it will be seen that its great merits are that pioneers in development have their reward in a superior and unassailable right; that rights are almost automatically acquired; that a limit to the development of a stream is also automatically demonstrated; and that the right is quite independent of the position of a scheme along a river, the upper proprietors having no advantage by reason of their more favourable position. It may be urged against this method that the existence of earlier and, possibly, less favourable schemes excludes the possibility of carrying out the most favourable scheme that could be devised for the whole use of the river. But what other methods would secure this without hampering development while waiting for the ideal scheme? Nor is any provision made for apportioning water among a number of people who may decide to carry out schemes at about the same time. The first to appropriate, even if he is first by only a day, obtains a prior right, and, so long as he proves beneficial use, he can appropriate as much of the water as is not already appropriated. This would appear to allow of large monopolies in water, but all the water-rights are attached to the land irrigated, and, as we have seen in the chapter on settlement, land can be acquired from Government only in limited areas, usually less than 320 acres.

It should also be noted that proportional division of the whole flow has been carefully avoided, i.e. no decrees take the form of allowing a scheme one-sixth or one-tenth or any other fraction of the whole flow of the river at all times. The disadvantage of the latter method, which at first sight appears very simple, is that every new scheme subsequent to division (especially above the older works) would destroy the practical working of the division, and readjustment of the whole division would have to take place at frequent intervals. A further disadvantage is that the limits of development are not automatically demonstrated. The prior appropriation method of defining the right by a definite measure of water, irrespective of the flow in the river and to be taken only after previous appropriators have taken their rightful measure, allows of more methodical and final determination of rights.

A great difficulty in the case of direct irrigation is to fix in a simple way the rate at which the water-right is proportioned to the area. Some figure must be used for the flow which will serve each acre. What will suffice for each acre is a very variable quantity at different times and in different parts even of the same scheme, depending on rainfall, soil, slope, crop, method of irrigating, etc. To adopt a variable figure depending on all these circumstances would be extremely difficult, and the policy adopted has been to fix a uniform maximum rate of flow to be allotted per acre, and this figure is usually on the liberal side. In Idaho it is $\frac{1}{50}$th cusec, and in Wyoming $\frac{1}{70}$th cusec.

This gives the means which have generally been adopted for defining a right by some absolute measure. It is a very wasteful method, however, and as streams are becoming more fully developed, it is being realized that some further limit is necessary. If the supply-curve of any canal for direct irrigation be studied, it will be found that it is never a straight horizontal line as represented in the previous diagrams, that is to say, that the canal does not run at its maximum capacity throughout the irrigating period. If, for example, a canal were to run at its maximum at the rate of $\frac{1}{50}$th cusec per acre throughout the 168 days, the application to the land would amount to nearly $6\frac{3}{4}$ feet, and, if allowed throughout the whole year, to over $14\frac{1}{2}$ feet—absurdly high figures. Some other limit must be fixed besides this single maximum. A nearer approach to economy of water would be obtained by fixing, from observations on a number of canals, an average curve of use throughout the year, with a maximum varying from month to month. This was done, as we have seen, in the international agreement between the United States and Mexico on the Rio Grande scheme, but it is very nearly impossible because of the variable features on which the use depends, as, for example, rainfall, nature of crop, soil, slope of land, methods of irrigation, etc. Even on a scheme such as the Shoshone, where the rainfall is low and the conditions are fairly uniform, we have noticed great variation in the demand even in a month as indicated by "lucerne peaks." The only further limit which seems reasonable and practicable is to fix, as is now done for storage, a maximum to the total volume annually abstracted (say, in acre-feet per acre). The maximum volume, combined with the maximum rate of flow, would determine the right in absolute measure. This method would require continuous measurement of every canal. It would not increase the area that could be irrigated during the low-water period if the maximum of demand came at that time, but it would release at other times a far greater volume for storage, and would in this way increase the possibilities of a stream. No such method has yet been adopted, but it probably will be shortly, as the fact that a maximum is fixed for the flow does not necessarily mean that this maximum can always be used. Beneficial use is always the measure of a right. That the Courts can reduce the use below the maximum allowed is indicated by action taken on the Boise River where, during one very low year, the Court sanctioned a uniform reduction of rights from $\frac{1}{50}$th to $\frac{1}{83}$rd cusec per acre to give the later appropriators a chance during a period of great demand. This practice is a tendency towards proportional division of the whole flow, and, if generally adopted, would certainly make use of water more economical, but it would tend to destroy the security of old rights.

One of the chief difficulties where storage has become necessary is to separate the storage period from the period of direct irrigation and to fix the date at which the first reservoir appropriation should begin, as the first day of the year is not always the most favourable time to begin filling. In the northern States, such as Idaho and Colorado, irrigation cannot be carried out in winter, but even in these States difficulty is experienced in fixing the seasons, especially the end of the period of direct irrigation, as the use dwindles down in autumn, and in Colorado the practice of irrigating in late autumn for early spring crops is fairly common. In the extreme south of America, as irrigation is practised throughout the year, it is impossible to define a separate irrigation period, and storage must be allowed throughout the year after prior direct leading appropriations are satisfied.

There appears to be no limit set to the rate at which storage water can be taken, the only limit being to the capacity of the reservoir, so that an appropriation to direct flow following an appropriation for a large reservoir across the stream would be in a very uncertain position. I could not find an example of allocation to a large number of reservoirs and to direct irrigation furrows in mixed order of time on an intermittant stream, which are conditions likely to be met with in South Africa. The two rivers serving the Salt River and Rio Grande schemes are the nearest approaches to our conditions, but on each river the problem has been simplified by the construction of one huge reservoir capable of holding more than the whole average flow of the river and by combining in the scheme or buying out most of the older rights.

Mention was previously made of the system of exchange as practised with reservoirs on the Cache La Poudre River in Colorado and sanctioned by law. On this river the earlier development was in the lower reaches of the river where the appropriation by direct flow had reached a limit. At a later date the owners of the upper reaches wished to develop their lands, but reservoir sites were lacking above their lands, so that they were prevented from using the direct flow by prior appropriations lower down and from carrying out storage works by lack of suitable storage sites above. Between the lands of the upper and lower owners, however, there were several storage sites, and the upper owners constructed reservoirs here, obtaining rights to flood water, and (by arrangement with lower proprietors enjoying direct-flow appropriations) they are allowed during the irrigating period to take out water for their lands directly from the stream in exchange for the same flow returned to the river from the reservoirs.

State Supervision and Water Courts.

Although the acquisition of water-rights becomes more nearly automatic by the method of prior appropriation than by any other method, yet it was early realized in most of the States that some form of State control was necessary for systematic recording of the dates of appropriation, for proving the extent of beneficial use, and for supervising the actual distribution of water according to priorities. For this purpose the office of State Engineer has been created in most States. In some States (e.g. Wyoming) the State Engineer and a number of superintendents also constitute a Water Court, but in Idaho and Colorado, beyond giving evidence, the State Engineer does not take part in the adjudication of legal rights or in the settlement of disputes, which is done by the ordinary State Courts. It is worth noting, however, that in the last report of the State Engineer of Colorado, he recommends that a Water Court be established consisting of three judges, the State Engineer to be one, and the other two lawyers learned in irrigation law. Our South African Water Court, established by the Act of 1912, consisting of a lawyer, an engineer, and a private assessor, is therefore in keeping with, if not an improvement on, the very latest recommendation of the State Engineer of one of the leading States in irrigation development.

At present, however, in these two States the functions of the State Engineer are not to adjudicate water-rights, but only to supervise the acquisition and administration of these rights. But these functions are now carried out with such systematic thoroughness and detail that the records of the State Engineer's office will always be the chief factor in the actual adjudication of rights. The office of State Engineer is, however, of comparatively recent date, and irrigation development had proceeded for some time before the modern methods of control had been introduced, and to adjudicate the earlier rights is therefore usually a matter of greater difficulty.

All that was formerly required before construction was a public notice of intention to appropriate a certain flow. This was often measured in variable and uncertain units, and there was no supervision to see that works were diligently carried out or that beneficial use of the whole appropriation was proved within a reasonable time. A person wishing to appropriate a part of the flow later on, would therefore be in great uncertainty as to the extent of previous appropriations on a stream with a large number of old appropriations. To put matters straight he would have to bring a case before the Water Court against each of the old users for definition of rights, and the Court would then have to determine these from evidence as to date of appropriation and extent of beneficial use. The State has not the right through its State Engineer to request a Court to define the rights along a stream; such a definition can originate only from one of the aggrieved parties, who must name all other users as defendants. This state of affairs existed on the Boise River when the United States Reclamation Department decided to build the Arrowrock dam, and in order to define all the old rights along the river, the Reclamation Department have applied to the

Court for a definition of rights along the Boise River, naming over thirty irrigation companies and nearly eighty individual appropriators as defendants. A similar case is referred to under the Salt River scheme in Arizona State. If the modern methods of recording and supervising rights had been in force from the outset, such difficulties would not have been so great. It is therefore advisable to start some method of systematic record of appropriations as early as possible, and the following is an outline of the methods adopted in Idaho State.

The person who wishes to carry out a work must first make an application to the State Engineer on a printed form (for this and regulations, see Appendix). In this form he must give a map showing the location of the works and lands to be irrigated, a statement of the area to be irrigated, and the nature and cost of the works. If the work is a large one (requiring over 25 cusecs direct flow or 6250 acre-feet of storage), the map must be prepared by an engineer. This application must be accompanied by fees in proportion to the appropriation—for direct flow $1 for the first cusec and 10 cents for each additional cusec, and for storage $1 for the first 250 acre-feet and 10 cents for each additional 250 acre-feet.

The State Engineer does not inspect the proposed works, but merely examines the application form to see that it is correctly filled in, and if it is in order he records it and issues a permit to the applicant to construct the proposed work. Before a final "licence" is issued, the applicant has to prove diligent construction and beneficial use by fulfilling the following conditions:—

(1) Construction must actually begin within sixty days of the issue of permit, and must be continued diligently and uninterruptedly till completion. For the larger works a bond is required as security.

(2) A time not exceeding five years is fixed by the State Engineer for completion of works, and one-fifth of the work must be completed within half the time allowed.

(3) After completion of the works another six years are allowed as a maximum for proving beneficial use by actual cultivation of the land. Only four years were formerly allowed for this, but it has been found necessary to extend the time to six years.

Thus a maximum of eleven years is allowed an applicant in which to perfect his right and obtain his "licence." During this period the State Engineer sees that the conditions are fulfilled. Thus at least six weeks before the time fixed for completion of works the person holding a permit must notify the State Engineer that he is prepared to prove completion, and public notice of this must be given for four weeks in a local newspaper. The State Engineer may, for larger works, demand completion profiles and cross-sections and an actual running of the canal to full capacity. In this way he tests the capacity of the works, and if he finds it less than declared in the application, he substitutes the smaller capacity for the original figures in the permit. In a similar way within the time fixed for proof of beneficial use, after public notice the State Engineer satisfies himself that the water is being used at the places named and for the purpose originally intended, and that the area is properly cultivated and irrigated. He then issues a final "licence" in accordance with his finding. The applicant or any one else can appeal to the Courts against his finding within sixty days of issue or refusal of licence. This "licence" then determines the measure of the right, and if all the conditions have been fulfilled it dates from the date of his first application for permit. Non-use for five years involves loss of "licence." Any subsequent enlargement of the works has to pass through the same process, and an additional "licence" is obtained separate from the former and in priority ranking after all applications between the original and the new application. These licences are not actual decrees, but they will have all the force of such unless upset by Court, and they will always be the most important evidence when any dispute is brought into Court. In Idaho, alone, during 1912, the State Engineer received 3512 applications for permits, proof of completion of works was offered for 664 cases, and final licences were issued for 497 cases. This work alone occupies a considerable staff in the State Engineer's Office, where most elaborate and modern card-indexed filing systems are employed, arranged according to names of applicants, rivers, and districts.

Other work of the State Engineer is the supervision of Carey Act schemes and also the distribution of water according to priorities. This latter is one of the most important functions of the State Engineer, and for this purpose an enormous field force of assistants is required. The whole is controlled by a board consisting of the State Engineer and three Water Commissioners, each in charge of a division of the State. Each division is divided into separate river districts which make convenient units. There are over forty of these districts in Idaho. Each district appoints its own water master and as many assistants as required by vote, every ⅕ cusec right carrying one vote. These officials are only called out when there is scarcity of water, and when two or more appropriators apply for them. Their pay is pro-rated among the users according to the volume of water supplied to each.

The law makes it compulsory for every user to have a permanent head-gate and measuring weir or flume to his work; all the head-gates must be provided with locks and keys, which are held by the water master.

Some such control is absolutely essential on the more fully developed rivers, as the problem of proper distribution according to priorities is then usually a most complicated one. Not only has every canal flow to be measured, but the river flow has to be measured at numerous points to determine seepage losses and gains, and telephonic communication along the river is almost essential. The problem is especially difficult where storage works are numerous and where the stream itself is used to convey storage as well as direct-flow water. An example of this was given on the Snake River where a storage work is constructed near the head of the river for lands some 250 miles lower down. The storage water has to be passed down this length, and at the same time the prior rights of some fifty users have to be satisfied as if the storage waters were not mingled with the ordinary flow, and seepage losses and gains, which are considerable along the whole length, have to be allowed for.

It is provided by law that the State Engineer should also collect hydrographic data on all the streams of the State, but sufficient funds have never been provided for this necessary and useful work.

The above outline of the modern development of the doctrine of prior appropriation has been given in some detail, as it is one of the few original schemes worked out by a country which, like South Africa, has a water supply insufficient for the whole irrigable land. In California the old riparian-right doctrine still has considerable force, but so modified and uncertain that it is impossible to deal with it briefly.

APPENDIX.

Giving Rules and Regulations of Appropriation and Specimens of Application Form and Card-index for Idaho State.

Effective March 19, 1913.

STATE ENGINEER'S OFFICE.

RULES AND REGULATIONS RELATIVE TO APPLICATION FOR PERMIT TO APPROPRIATE THE PUBLIC WATERS.

The laws of the State authorize the appropriation for beneficial use of the waters of any natural stream, springs or seepage waters, lakes, or other public waters. Any person intending to appropriate water must file with the State Engineer an application for permit in accordance with the following instructions.

The application blank must be filled in legibly with ink, or preferably on typewriter. If it is found that the ruled lines in any paragraph of the blank are insufficient the space under the head of Remarks may be used, proper reference thereto being made in such paragraph by the expression "See Remark No. 1," "See Remark No. 2," etc.

As to Application Blank.

Each of the following instructions refers to one of the nine main paragraphs into which the application blank is divided.

1. Insert name of applicant, his post office address, and county of residence. Subdivisions "I" and "II" are only to be filled in when applicant is a corporation.

2. State the quantity of water claimed in cubic feet per second, one cubic foot per second, the equivalent of 50 miners inches measured under a 4-inch pressure, being a maximum allowed for the irrigation of 50 acres, except in very unusual cases.

If flood or winter flow waters are claimed for storage, specify in acre-feet the quantity claimed, not to exceed 5 acre-feet of water per acre of land to be irrigated. If both normal flow and flood and winter flow water are claimed the total amount of water claimed must not exceed the equivalent of a continuous flow, during the irrigation season, of more than one cubic foot per second for each 50 acres of land to be irrigated or more than 5 acre-feet of stored water for each acre of land to be irrigated.

3. Give the name of stream or lake constituting the source of supply. If the source of supply is a spring or seepage water, give legal description of the 40-acre tract in which it is situated; if an unnamed stream or lake, insert the words "unnamed stream" or "unnamed lake." Where two or more sources are claimed, name or describe each separately and specify the amount of water claimed from each.

4. When the amount claimed does not exceed 25 cubic feet per second or 6250 acre-feet and point of diversion is on surveyed land, locate same by giving the legal description of the 40-acre tract in which it is situated. If upon unsurveyed land, give approximate distance to the mouth of stream from which water is claimed, or to the mouth of some creek flowing into said stream in the vicinity. Where there is more than one point of diversion, number and describe each separately, and place such diversion numbers on the maps. In case of spring on unsurveyed land, tie to some permanent and prominent landmark.

Where the water claimed exceeds 25 cubic feet per second, or 6250 acre-feet, the above instruction is sufficient for temporary filing. At the time of filing completed application, point of diversion is to be located as follows: If upon or near surveyed land, tie point of diversion by course and distance to section or quarter section corner and insert such tie in paragraph 4 of the blank, or if there is not sufficient room in said paragraph tie should be as required for the location of diversion-point given in the instruction under paragraph 4. If point of diversion is more than two miles from a corner of a public survey, the tie may be made to the mouth of the stream from which the water is claimed or to the mouth of some creek flowing into said stream. In cases of springs tie by course and distance to some permanent and prominent landmark.

5. State purpose for which water is to be used and fill in the particular sub-divisions referring to such use. If water is to be used for other than irrigation or domestic purposes, locate the point of return to stream, if there be such, and the point of use in the same manner as required for the location of diversion point given in the instruction under paragraph 4.

6. Give estimated cost of all construction work necessary to conduct water to place of use, including dams, ditches, flumes, etc. This should not include installation of machinery.

7. In sub-division "I" state generally what diversion works will be constructed. In sub-division "II" give the dimensions of the works as indicated by the various blanks and give legal descriptions of the quarter sections crossed by conduit. Where water is to be used for irrigation, legal descriptions must be given of all quarter sections to be crossed by main ditch and laterals designed to deliver water within one mile of each 160-acre tract of the lands to be irrigated. Route of main ditch should be described first, followed in turn by each lateral.

8. State time necessary to complete diversion works not exceeding five years. Full length of time will not be allowed where it appears that by diligent prosecution of construction the work could be completed in less time. If more time than could be reasonably required under ordinary circumstances is asked for, submit with the application a letter setting forth particular reasons why the time asked for should be allowed.

9. State the time necessary to put water to beneficial use after the completion of the works, not exceeding six additional years. The same rule as above applies to this paragraph.

As to Maps.

A. Before permit will be granted applicant must file with the application two maps, showing the following details:—

1. If for irrigation and domestic use:
    - (*a*) Name of applicant.
    - (*b*) Section, town, and range numbers where public survey has been made.
    - (*c*) Source or sources of supply.
    - (*d*) Point or points of diversion.
    - (*e*) Reservoirs, if any.
    - (*f*) Route of ditch or ditches, including laterals delivering water within one mile of each 160-acre tract of the lands to be irrigated.
    - (*g*) Lands to be irrigated to be shown by check mark, thus ✓, in each 40-acre tract, any part of which is to be irrigated.

2. If for other than irrigation and domestic purposes:

- **(*a*) Name of applicant.**
- **(*b*) Section, town, and range numbers where public survey has been made.**
- **(*c*) Source or sources of supply.**
- **(*d*) Point or points of diversion.**
- **(*e*) Route of ditch or ditches.**
- **(*f*) Point or points of use.**
- **(*g*) Point or points of return to stream after use.**

B. If application is for more than 25 cubic feet per second, or more than 6250 acre-feet, the maps must be prepared from actual survey and must be certified to by engineer in charge of survey in the following form:—

I hereby certify that this map was prepared from an actual survey made by me ....191...and correctly shows position of points indicated thereon.

..

Engineer.

P.O..

Date..191...

General.

I. At the time of filing the application with the State Engineer, the following fees must be paid:—

For a normal flow right, $1.00 for the first second foot and 10 [illegible] additional for each additional foot or fraction thereof.

For a flood and winter flow right for storage purposes, $1.00 for the first 250 acre-feet claimed and 10 cents additional for each additional 250 acre-feet or fraction thereof.

II. Application will be accepted temporarily provided application blank, accompanied by fees, be filed containing the information required in paragraphs 1 to 4 inclusive, and a statement under paragraph 5 as to the purpose for which water is claimed. Applicant will then have sixty days from the date application is mailed to him by the State Engineer for completion, within which to run surveys, where required, prepare maps, and return completed application, together with maps. However, it is best to submit maps when application is filed, in all cases where a survey is not required, that is, where the amount claimed is not more than 25 cubic feet per second or 6250 acre-feet.

III. Where the waters of a spring or lake, not exceeding 5 acres in surface area at high-water mark, are sought to be appropriated and such spring or lake is upon land in Government or State ownership or owned by the applicant, a statement to that effect should be made under the head of Remarks. If such land is owned by another than the applicant, a statement should be made to the effect that he has given the applicant written permission, and that such permission has been executed and acknowledged as required for the conveyance of real estate.

IV. The space under the head of Remarks is to be used for matters strictly pertaining to the application. It must not be used for letter-writing.

No..............

APPLICATION FOR PERMIT.

TO APPROPRIATE THE PUBLIC WATERS OF THE STATE OF IDAHO.

1. Name of Applicant:...

Post Office Address: ....

County:.. State: ....

I. If applicant is a corporation, give:

(*a*) Date and place of incorporation:..

(*b*) The amount of capital stock:...

(*c*) The amount paid in:...

(*d*) Names and addresses of directors:..

....

....

II. The financial resources of the applicant are:

(*a*) Cash on hand:..

(*b*) Treasury stock: ....

(*c*) Bonds to be issued:...

(*d*) Other resources:...

....

2. The quantity of water claimed is...cubic feet per second.

3. Source of water supply:...

4. Location of point of diversion:...

County of...

5. To be used for:...

I. Irrigation and domestic use:

(*a*) Amount of land to be irrigated:...acres.

(*b*) In the following legal sub-divisions:...

(A list of the lands to be irrigated may be appended as a part of this application.)

....

....

II. Mining, milling power, manufacturing, transportation or other purposes:

(*a*) At what point:..

(*b*) Amount of power to be generated..............H.P. under..............ft. head.

(*c*) Is water to be returned to any stream:...

(*d*) If so, name stream and locate point of return:..

....

6. Estimated cost of works: $....................

7. Description of works for diversion:

I. Kind of works:..

(Reservoir, dam, ditch, flume, pipes, or otherwise.)

....

II. Dimensions of work:

(*a*) Height of dam..............feet, length of dam at top..............feet, length of

(If height of dam will exceed 10 feet, send to State Engineer's Office for Regulations.)

dam at bottom..............feet. Material used in construction...................

....

(State whether wood, earth, stone, or concrete).

(*b*) Capacity of reservoir..................................acre-feet.

(*c*) Size of headgate: Width..............feet, height..............feet.

(*d*) Conduit......................., width at bottom.................feet, width at water

(State whether ditch, flume, or pipe.)

line..............feet, depth of water..............feet; diameter of pipe........... inches; average grade per mile is...................feet. Length of conduit is ....miles, and it crosses the following quarter sections:....................

....

....

....

....

8. The time required for the completion of the construction of such work is..............years.

9. Time required for the complete application of the water to the proposed use is............. additional years.

Be it known that the undersigned hereby makes application for a permit to appropriate the public waters of the State of Idaho as herein set forth.

....

Applicant.

By...Agent.

Remarks: ....

....

APPROVAL OF STATE ENGINEER.

The number of this permit is..................

Recorded in Book....................Page............Approved..

This is to certify that I have examined the within application for a permit to appropriate the public waters of the State of Idaho, and hereby approve the same, subject to the following limitations and conditions:

Bond in the sum of $.................to be filed on or before.......................................

Work to begin on or before................................, and to continue diligently and uninterruptedly to completion, unless temporarily interrupted by circumstances over which permit holder has no control.

One-fifth of the work above specified to be completed on or before..........................

The whole of the said work to be completed on or before.......................................

Beneficial use of water appropriated in accordance herewith to be made on or before

....

Witness my hand this.......................day of..,.....

....

State Engineer.

Specimen of Card-index for State of Appropriation of a Stream.

Stream**...** **...County.**

Name.	Decree.			Application.		Permit.		Licence.		Priority.		
	Vol.	Fol.	Sec. Ft.	No.	Sec. Ft.	No.	Sec. Ft.	No.	Sec. Ft.	Mo.	Day.	Year.
Total ...												

CHAPTER XIX

SUMMARY OF IMPORTANT POINTS

Situation, Climate, and Water Supply.

THE schemes described are all in the west of America, and extend from latitude 46 degrees to latitude 31 degrees, or over a total distance from north to south exceeding 1000 miles. The elevation of the lands irrigated varies from below sea-level to 5000 feet above sea-level. In the north the winter is extremely cold, and temperatures as low as —35° F. are experienced, the summer is short and hot, and the irrigating period extends from about 15th April to 1st October. In the extreme south frosts are uncommon, temperatures up to 125° F. are experienced, and irrigation is practised throughout the year.

The mean annual rainfall varies from 2½ inches to 15 inches. On three schemes the rainfall is below 5 inches, on three others it is between 5 inches and 10 inches, and on the majority it is between 10 inches and 15 inches.

On most of the schemes the rain falls regularly in winter or spring. Towards the south-east, however, summer rains are usual, e.g. on the Rio Grande scheme. The Salt River scheme enjoys both winter and summer rains.

Most of the streams derive the major portion of their waters from melting snows, and in consequence the flood season is very definite, and the variations in total run-off from year to year are very small. This is more noticeable in the rivers of the North, where during periods of over ten years the maximum annual run-off seldom exceeds three times the minimum. In the South, where melting snow plays a smaller part, the variation is greater. Thus on the Salt and Rio Grande Rivers the maximum annual run-off is more than twenty times the minimum.

The mean annual run-off per square mile of drainage depends of course on the catchment area. It is greatest in the smaller areas and close up to the steep snow-capped ranges. Thus on the Shoshone and Tuolumne Rivers, each with a drainage area of 1500 square miles, it is as high as 700 and 1200 acre-feet per square mile. Even on the Snake, with a drainage area of 16,000 square miles, it is 400 acre-feet. On the rivers in the South, however, it is generally much less, especially on the larger rivers, such as the Colorado and Rio Grande, where it does not exceed 60 acre-feet; and, on an intermittent river such as the Humbolt in the Great Basin, it is only 13 acre-feet, which is roughly the value at Van Wyks Vlei in the Cape Province.

The maximum intensity of flood is reached in the rivers of California, which come down from the steep and bare granite slopes of the Sierra Nevadas. On these rivers a maximum intensity of from 25 to 40 cusecs per square mile has been recorded, whereas the maximum intensity for the larger and flatter rivers, such as the Colorado and Rio Grande, does not exceed 1 cusec per square mile.

Engineering Works.

RESERVOIRS

(*a*)—Earthen Dams

Of the earthen reservoirs three have a greater height than 100 feet, and one of these is built without a core-wall. The most interesting is the Lahontan dam on the Truckee-Carson scheme. Very great care is taken in the selection and mixing of materials for the bank. The belt-system has been used for both conveying and mixing the materials. Drainage is usually provided in the down-stream portion of the base.

(*b*)—Masonry Dams

The arched type of dam appears to be favoured even where the width of the gorge at crest-level is as great as 985 feet, and where the section is designed to be strong enough as a gravity-section.

A stress of 23 tons per square foot on horizontal planes in the masonry is allowed, and this greatly exceeds the limits set in other countries.

In the latest dams a very extensive system of drains is provided near the up-stream face both in the foundations and in the masonry. Large inspection galleries also run through the length of the dam near the up-stream face.

A good example of modern methods of construction will be found in the Arrowrock dam. The outstanding points are:—Sand-cement is widely used; cobbles are passed through the mixers; overhead cable-transport is usually provided; concrete is deposited through shoots wherever possible; cement is blown through pipes; conveyor-belts, bucket-ladders, and dragline excavators or graders are also freely used for transporting materials.

The designs adopted for spillways in unfavourable situations are also interesting. A semi-circular weir is adopted at Bellefourche, a tunnel at Shoshone, a deep channel behind a weir at Arrowrock and Oakley, and a lined shoot with drops at Lahontan.

In valve-design there is a tendency to provide each valve with a separate tunnel through the dam. The lowest sluicing-valves are often of the usual sliding-gate type worked by hydraulic rams situated in chambers above the gates and directly connected with them. The most interesting regulating type is the "Ensign" needle-valve. The "ring" type adopted at Oakley and Lahontan is also of great interest.

Headworks and Regulators.

Examples of overflow masonry weirs will be found in the Lagrange weir (Modesto-Turlock scheme), 127 feet high, and in the Bellefourche, Boise, and Granite Reef (Salt River scheme) weirs which are of considerable height and built on poor foundations. The Corbett weir (Shoshone scheme) is an example of a reinforced concrete structure on a poor foundation. The Minidoka and Milner types illustrate the method of blocking the ordinary channel of the river by means of high rock-fill dams and turning the water over weirs constructed on the flat banks or on islands. The Laguna weir (Yuma scheme) is of a type common in India and suitable for very wide rivers with poor foundations.

Regulators for weirs and canals do not present many new features. The radial gate is very common and is sometimes balanced, and, on the Modesto-Turlock scheme, is provided with an automatic adjusting device. The rolling gate on the Boise weir is an interesting example of a type common in Germany. In the muddy waters of the Colorado, Stoney sluice-gates are adopted, and horizontal stop-planks at the entrance to the canals allow only the upper and clearer water to enter. The ring-gate at the entrance to the siphon on the Yuma scheme is interesting.

Canals and Structures.

The main canal is usually designed with a capacity at the head at the rate of 1 cusec for between 50 and 100 acres. The ratio of width to depth is usually smaller than is found in India. The highest ratio is 12, on the Yuma canal, where the slope is small and the waters muddy. It is 10 on the big Twin Falls canal, but is generally less than 5 for canals of smaller capacity than 1000 cusecs. The losses in canals are usually expressed in cubic feet per day per square foot of wetted surface in the canal. This figure was for the Minidoka scheme between 0.20 and 2.06, and for the Truckee-Carson scheme from 0.52 to 1.51. It varies from about 0.20 for clay soils to 5 or 6 for sandy soils as in California, and an average value is about 1. Several canals have been lined with concrete to prevent loss.

Most of the recent structures are of reinforced concrete. For flumes, the Maginnis or Hess type is very generally used and is cheap. Checks, often of a temporary nature, have been found necessary on canals which, owing to slow settlement, serve a smaller area than that for which they were designed. For small head-gates to farmers' streams a common type has the gate set at the slope of the bank; perhaps the cheapest type is that described on the Imperial Valley scheme.

Soils.

Physical analyses have been given for the Bellefourche, Truckee-Carson, Modesto-Turlock, and Imperial Valley schemes, and of the experimental soil at Logan. On every scheme we find several types of soils. The most compact soils are on the Bellefourche and Imperial Valley schemes, and in both cases the underlying formation provides poor drainage. The heavier soils on other schemes, such as the Huntley, Shoshone, and Salt River, are very often of no great depth and have a gravel sub-soil. The "gumbo" soil at Bellefourche contains 35 per cent. of clay and 43 per cent. of silt, and the heavy soil of the Imperial Valley contains 29 per cent. of clay and 63 per cent. of silt. The California soils, on the other hand, are sandy. A common soil on the Modesto-Turlock scheme contains only 1.7 per cent. of clay and 7.4 per cent. of silt, the rest being sand. Hard-pan very often underlies the sandy soils. Between these two extreme types of clay and sand are many excellent soils. The soil at Logan represents a very good type. Alkali is usually found in most of the soils in varying quantities. In the more open type of soil it seldom exceeds .2 per cent. Only in the heavier types and in flat depressions does it exceed .4 per cent. and become dangerous.

Surface-Slope and Methods of Irrigating.

The flattest lands are on the north of the Minidoka scheme, where the slope is but 1 foot per mile. Slopes of 6 feet or less per mile predominate on the Truckee-Carson scheme, on the Modesto-Turlock and Fresno schemes in California, and on the Yuma and Imperial Valley schemes. Medium slopes of about 20 feet per mile prevail on the Shoshone, Huntley, and Salt River schemes, and the steepest slopes of from 70 to 100 feet or more per mile are found on the Twin Falls and Redlands schemes and on large parts of the Bellefourche and Boise schemes.

By far the commonest method of applying the water to the land is "surface-flow between borders." The beds are usually made very long and narrow. Some beds are as long as half a mile, but a common size adopted is about 300 yards long and 20 yards wide. This system involves the least expense in laying out a farm, as the cost of levelling the land and of constructing furrows is reduced to a minimum. A smaller application, and therefore a greater economy, of water would probably be obtained if the beds were made shorter or if the "basin-soakage" method were adopted. The latter method is found only on the flattest lands where the slope is insufficient for surface flow (usually less than 6 feet per mile), as on the Truckee-Carson and Modesto-Turlock schemes. Other methods, such as "simple surface flow" and terracing, are being gradually abandoned. The "corrugation" method is very common for orchards and for such crops as vegetables, sugar beets, and cotton, but the most interesting use of this method is on light soils which have too steep a slope to stand "surface flow between borders" without scouring. Very large areas of lucerne are irrigated in this way on the Twin Falls and Boise schemes. In connection with the corrugation method, the system of pipe-distribution described on the Redlands scheme is instructive as showing to what lengths it is possible to go in preventing loss of water. The size of the irrigating stream employed for surface flow between borders is usually between ½ and 3 cusecs. On slopes of 6 feet or less per mile there is a tendency to use much larger streams. On the Yuma, Modesto-Turlock, and Truckee-Carson schemes the streams applied are as great as 12, 15, and even 20 cusecs. With such big streams a rotation system of distribution is necessary, and even where smaller streams are used rotation is being gradually introduced.

The difficulties experienced in working out a satisfactory rotation scheme are very great, especially where there is a large area of vegetables or where there are "peaks" of demand, such as were noticed on the Shoshone scheme. The settlers generally object to rotation, and particularly to long-period rotation. On the Yuma and Truckee-Carson schemes the period is seven days, on the Huntley four days, and on the Shoshone five days. The longest period is three weeks or one month on the Modesto-Turlock scheme.

The following methods of rotation have been adopted:—

(1) Supplying all minors, but only half the users on each, during one period, as at Huntley.

(2) Supplying half of the minors during one period, and keeping the remainder dry, as at Truckee-Carson.

(3) Where big irrigating streams are used, a limited number of users on each minor is supplied in turn, beginning *at the bottom* of the minor and working up, as at Yuma.

(4) Where the supply is limited and big irrigating streams are used, as on the Modesto-Turlock scheme, rotation proceeds *from the top* of the system and from the top of each minor, a fixed size of stream being supplied to each user for a period proportional to his area and to as many users as the whole available volume of flow at the time will allow at this fixed rate per user.

Drainage.

From American experience we learn that drainage works have become necessary on some portion of the area of most schemes, and often where least expected. On at least seven of the schemes which we have considered expensive drainage works have already been carried out, although the schemes are still fairly young. Shallow open drains have generally failed to afford a complete remedy, and the common practice now is to use pipe-drains wherever the slope is sufficient and to place these at a depth of at least 8 feet below the surface, and preferably in a pervious sub-soil layer such as gravel. The Shoshone and Huntley schemes afford good examples of such drainage. The cost is found to be about \$1½ per foot length of drain. If the drains are placed half a mile apart the cost will therefore amount to \$25 per acre, without allowing for smaller feeder drains which will probably be necessary.

In the original estimate of expenditure for a scheme it is therefore advisable to anticipate that a certain proportion of the area will become seeped and will require drainage works costing at least \$25 per acre drained. Preventive measures should be adopted at the outset. Canals which run in very pervious materials should be lined, and extravagant use of water by the settlers should be prevented.

Crops.

Lucerne occupies by far the largest portion of the whole area irrigated. In some of the northern schemes cereals occupy a larger area than lucerne. In California orchards are of greater importance. Near sugar factories, as at Huntley, sugar beets occupy the greatest area. But lucerne is found on all schemes, and on some, such as the Truckee-Carson and Modesto-Turlock schemes, occupies nearly three-quarters of the area irrigated. In the more northern schemes it does not give more than three cuttings a year, with a total average weight of from 2 to 4 tons. It sells at from $5 to $7 per ton in the stack and about $3 more baled at the rail. In the most southerly schemes it gives about twice as many cuttings and about twice the weight, and realizes from $7 to $10 per ton at the stack. It generally requires two waterings per cutting in the hotter months, but we have noticed that in the South there is a period during the hottest months when it makes very little growth, and water is often withheld during this period. On some of the northern schemes, where lucerne occupies the largest area and spring rains start all the lucerne growing simultaneously, we get a series of "peak-loads" in the supply-curve between the times of cutting. It is difficult to meet the simultaneous demand, even with a system of rotation, and the distributing canals must be made of large capacity.

Other crops even more profitable than lucerne are vegetables, fruits, cotton, and sugar beets. Vegetables bring in very high returns, but generally the area occupied by them is a small portion of any scheme on account of the limited market.

Fruits occupy the greater area in many Californian schemes. Grape and other fruit cultivation is described on the Fresno scheme. Oranges occupy most of the area on the Redlands scheme, and the melon crop of the Imperial Valley scheme is worthy of note. In the North, apples are the chief orchard crop, and the varieties "Rome Beauty" and "Jonathan" thrive very well in the colder climates.

Cotton cultivation is extending rapidly in the South, and is described in the Imperial Valley scheme. Sugar beets seem to thrive best in the colder climates of the North, but are also grown in the warmer climates. The methods of cultivating sugar beets are described in the Huntley scheme. It appears to be necessary to have a sugar factory close to the fields, and usually within 30 miles of them.

Settlement.

This has been dealt with in a separate chapter. One of the most important lessons is that the supply of settlers with sufficient experience and capital is limited. The result is that settlement is slow, and considerable difficulty is generally experienced during the first few years in getting instalments of the cost from the settlers. Another useful lesson is that where private capital is invested in settlement schemes there is a tendency for the State to exercise some sort of control. Perhaps nothing has kept back progress in irrigation settlement more than the many failures of uncontrolled schemes of speculators, who either deliberately or through lack of proper investigation have over-estimated the possibilities of a limited supply of water. Few of the settlement schemes are more than ten years old. Most of them are still in process of development, and it is therefore too early to form a fair judgment as to the results that can be achieved.

Cost.

It is remarkable on how many irrigation works the actual cost has exceeded the estimate. Drainage, as we have seen, adds greatly to the expense of a scheme. On large reservoirs failures of contractors or untimely floods have very often added considerably to the cost. The number of necessary minor structures, such as bridges, culverts, etc., is also often under-estimated. The cheapest schemes are usually the oldest, which irrigate the easier lands and do not require storage.

The cost of the Reclamation Service schemes varies from $30 to $70 per acre, and an average cost per acre would be about $50. The cost to the settler of the Carey Act schemes varies from $25½ to $65½ per acre. The distributing system of these schemes is not carried out in such detail as for the Reclamation schemes. In both cases, however, it should be remembered that the settler makes practically no payments for the land.

Many of the private schemes at first sight appear to be much cheaper. But to compare them with the above figures certain circumstances must be considered. Thus, although the Modesto and Turlock schemes cost only $20 and $10 per acre respectively, the minor distributing system has to be constructed by the settlers, expensive works are still required to enlarge the capacity of the canals and storage reservoirs, and the land is not obtained free of cost. On the Fresno scheme, although the charge for water-rights is only $5 to $10 per acre, a perpetual annual charge of about 70 cents per acre is made and the minor distributing system has to be constructed by the settlers. On the Imperial Valley scheme, although the mean charge for water-rights is only $12 per acre, the settler has, in addition, to pay for all water used at the rate of 50 cents per acre-foot, and a large outlay is still necessary to complete the scheme. On the Reclamation schemes, for which a building charge has not yet been fixed, water is sold in bulk at rates varying from 40 cents to $1 per acre-foot. The most expensive scheme is at Redlands, where the charge for water appears to reach the high figure of $12¼ per acre-foot. The annual maintenance and operation charge on all the schemes appears to vary from 35 cents to $1.80 per acre included in the whole scheme—$1 per acre would probably be a fair average. During the early years, before the whole area is taken up by settlers, the cost of maintenance per acre actually irrigated is very much higher, and in one case reached $7 per acre.